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Evaluation of Nutritive Values of Different Varieties of Barley for Ruminants: Modeling Nutrient Supply, Degraded Protein Balance, Metabolizable Protein, and Microbial Protein Synthesis

ADF Project # 20050740

Final Report

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By

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Abstract

The objectives of this research program were to determine the effects of hulled barley variety collected at three consecutive years, grown in Saskatchewan on detailed chemical and nutrient profiles for ruminants and to determine the magnitude of differences between the barley varieties and between feed-type and malting-type barley.

Results indicated that there were significant effects of hulled barley variety and years on chemical characteristics, protein and carbohydrate fractions, total digestible nutrients (TDN), energy values (DE_{3X}, ME_{3X}, NEL_{3X}, DE_{4X}, ME_{4X}, NE_{4X} for dairy; DE, ME_m, ME_g for beef), in situ degradation kinetics of dry matter and crude protein (Ørskov's Model) and starch (Tamminga's Model), predicted nutrient supply, degraded protein balances (DPB), metabolizable protein (MP) and microbial protein synthesis (MCP). All barley varieties had negative degradation balances indicating potential nitrogen shortage in the rumen.

In conclusion, the hulled barley variety and year affected the chemical and nutrient profiles, digestive behaviors, nutrient supply and availability in ruminants.

The information obtained from this research can be used as an aid in barley breeding program to select superior hulled barley variety in Saskatchewan and can be used to assist nutritionists in designing lost cost and efficient feeding programs.

Executive Summary

This final report provides information on the completed status of this project. Dr. Kenton Hart (PhD from UK) and Dr. Daal Damiran (PhD from USA) were hired as PDF research fellows for the project.

In the first project, we did four studies. We studied the effects of barley genotype (grown in Saskatchewan and collected at three consecutive years) on detailed chemical characterization and protein and carbohydrate fractions using the CNCPS system. We studies the effects of genotypes (grown in Saskatchewan and collected at three consecutive years) on total digestible nutrient (TDN) and estimated energy value (DE_{3X}, ME_{3X}, NEL_{3X}, DE_{4X}, ME_{4X}, NE_{4X} for dairy; DE, ME_m, ME_g for beef) of barleys using NRC-2001 and NRC-1996 summary approach. We studied the effects of genotypes (grown in Saskatchewan and collected at three consecutive years) on in situ degradation characteristics/ kinetics of nutrient components of barleys. We also studied the effects of genotypes (grown in Saskatchewan and collected at three consecutive years) on predicted nutrient supply to ruminants: degraded protein balance (DPB), metabolizable protein (MP) and microbial protein synthesis (MCP) of

barleys using modeling approaches. This work and findings have been published as a peer-reviewed full research paper by the Canadian Journal of Animal Science (CJAS). 88:711-719 and the results presented in the Joint Annual Conference of the American Society of Animal Science (ASAS) and American Dairy Society Association (ADSA) and the Soils and Crops Conference in Saskatoon.

Project 1. Chemical Characteristics, Protein and Carbohydrate Fractions, Energy Values, In Situ Ruminal Parameters, Degraded Protein Balance, Metabolisable Protein and Microbial Protein Synthesis of CDC Developed Barley for Cattle: Comparison of the Malting Cultivar and Five Feed Cultivars; Comparison between barley Genotypes.

- Study 1. Effects of genotypes collected at three consecutive years on detailed chemical characterization and protein and carbohydrate fractions of barleys using CNCPS system (completed).
- Study 2. Effects of genotypes collected at three consecutive years on total digestible nutrient (TDN) and estimated energy value (DE_{3X}, ME_{3X}, NEL_{3X}, DE_{4X}, ME_{4X}, NE_{4X} for dairy; DE, ME_m, ME_g for beef) of barleys using NRC-2001 and NRC-1996 chemical approach (completed)
- Study 3. Effects of genotypes collected at three consecutive years on in situ degradation characteristics/ kinetics of nutrient components of barleys (completed)
- Study 4. Effects of genotypes collected at three consecutive years on predicted nutrient supply to ruminants: degraded protein balance (DPB), metabolizable protein (MP) and microbial protein synthesis (MCP) etc of barleys using modeling approaches (completed).

In a second project, we did two studies. We studied the effects of genotypes collected at three consecutive years on carbohydrate and protein degradation ratios, nitrogen to energy synchronization: Effects of variety and growth year. We also studied the effects of genotypes collected at three consecutive years on hourly effective rumen digestion of barley: Effects of variety and growth year. This work and findings have been accepted as a peer-reviewed full research paper by Journal of Animal Physiology and Animal Nutrition. The results presented in the Joint Annual Conference of the American Society of Animal Science (ASAS) and American Dairy Society Association (ADSA) and have been accepted to present in the 11th International Congress on Amino Acids, Peptides and Proteins (11thICAAP) and the

Inaugural ASAS-CAAVM Pacific Rim Conference.

Project 2. An investigation of carbohydrate and protein degradation ratios, nitrogen to energy synchronization, and hourly effective rumen digestion of barley: Effects of variety and growth year

Study 5. Effects of genotypes collected at three consecutive years on carbohydrate and protein degradation ratios, nitrogen to energy synchronization (completed)

Study 6. Effects of genotypes collected at three consecutive years on hourly effective rumen digestion of barley (*Effects of variety and growth year*) (completed)

Research Progress

Introduction: Research Motivation and Background

As Ministry of Agriculture Strategic Research Chair in Feeds, one of my mandates is to increase feed and livestock production efficiencies through improved livestock product quality, reduced environmental impact and supported sustainable animal production. Feed is the largest single cost (75%) of production facing livestock feeding operations in Canada.

In western Canada, barley is the primary constituent of concentrate rations for dairy and beef cattle. Enhanced knowledge of genotypic differences of barley varieties and chemistry in relation to nutrient utilization in livestock will lead to more efficient feeding system for livestock and assist nutritionists in designing low cost, efficient feed programs and lead to a more competitive livestock feeding industry

There are two research strategies to improve nutritive of barley for dairy and beef cattle. The first one is to increase nutrient availability of barley through variety selection and/or barley processing. The second strategy is to improve the nutritive value by development of "DOUBLE LOW BARLEY" with low hull content and low content of hydroxycinnamic acids in the barley.

The proposed feed research program is to target the first strategic research area. In Saskatchewan, there are various varieties of barley available. However, the detailed nutritive values for ruminants between and within varieties of barley, as well as the effects by genotypes and/or environment, are not available in term of degradation kinetic, energy values for ruminants, nutrient utilization and potentially nutrient supply and availability. The magnitudes of differences between varieties in terms of detailed nutritive values are not available. The magnitudes of differences between feed-type and malting-type varieties in

terms of detailed nutritive values are not available.

There is an urgent need to obtain such important information for the crop livestock interface (CLI) database (which will be used by barley breeders, barley scientists, nutritionists, livestock producers and feed industry) and there is an urgent need to move forward to develop more efficient barley based diet for ruminant animals.

No systematic/complete research has been carried out to investigate the magnitude of the differences in the terms of the digestive kinetic, energy values and potential nutrient availability and supply to ruminants between and within varieties of barley as well as effects of genotypes or genotype and environment interaction.

Overall Project Objectives:

1. Long-Term: To screen the best variety of barley for ruminants and increase knowledge of the nutritional relevance of barley characteristics and chemistry and to apply this information to the production of high quality feeding programs through plant breeding/variety selection.
2. Short-Term: To determine digestive behavior and nutrient utilization of barley seeds in ruminants. COMPARISON of varieties of barley seeds and determination of effects of genotypes and year;
3. To estimate energy values of different varieties of barley for ruminants. COMPARISON of different varieties of barley seeds and determination of effects of genotypes and year;
4. To predict nutrient availability and supply to ruminants of barley seeds in ruminants. COMPARISON of different varieties of barley seeds and determination of effects of genotypes and year;
5. To continually provide Saskatchewan crop livestock interface database;
6. To provide information for feed and livestock industry to lead to more efficient feeding system for livestock and assist nutritionists in designing low cost, efficient feed programs and lead to a more competitive livestock feeding industry.

Completed Projects

Project 1: Chemical Characteristics, Protein and Carbohydrate Fractions, Energy Values, In Situ Ruminal Parameters, Degraded Protein Balance, Metabolisable Protein and Microbial Protein Synthesis of CDC Developed Barley for Cattle: Comparison of the Malting Cultivar and Five Feed Cultivars; Comparison between Barley Cultivars

This project was extracted from a peer-reviewed article published in the Canadian Journal of Animal Science (Kenton. J. Hart, Brian G. Rossnagel, Peiqiang Yu 2008, 88:711-719). It was extracted the following four studies:

Study 1. Effects of genotype collected at three consecutive years on detailed chemical characterization and protein and carbohydrate fractions of barleys using CNCPS system (completed).

Study 2. Effects of genotypes collected at three consecutive years on total digestible nutrient (TDN) and estimated energy value (DE_{3X}, ME_{3X}, NEL_{3X}, DE_{4X}, ME_{4X}, NE_{4X} for dairy; DE, ME_m, ME_g for beef) of barleys using NRC-2001 and NRC-1996 chemical approach (completed)

Study 3. Effects of genotypes collected at three consecutive years on in situ degradation characteristics/ kinetics of nutrient components of barleys (completed)

Study 4. Effects of genotypes collected at three consecutive years on predicted nutrient supply to ruminants: degraded protein balance (DPB), metabolizable protein (MP) and microbial protein synthesis (MCP) etc of barleys using modeling approaches (completed).

Project Summary

The objective of this experiment was to compare the chemical composition, protein and carbohydrate fractions, energy values, in situ rumen degradation characteristics, predicted nutrient supply, degraded protein balance, metabolisable protein and microbial protein synthesis of five feed type cultivars of CDC developed barley in comparison to Canada's most widely grown malting cultivar AC Metcalfe. The chemical composition of the barley cultivars was fairly consistent with the largest differences being observed in starch

(492 to 537 g/kg DM), non structural carbohydrates (655 to 723 g/kg DM) and NDF (122 to 193 g/kg DM). There were no differences observed between AC Metcalfe and any other cultivar in respect to crude protein, acid detergent lignin, soluble crude protein, non protein nitrogen or fibre bound protein. There were no differences in protein fractions partitioned using the Cornell Net Carbohydrate and Protein System (CNCPS). However, there were differences ($P < 0.05$) in the CNCPS carbohydrate fractions with shifts in the proportions of rapidly, intermediately and slowly degradable carbohydrate. Cultivars CDC Cowboy, CDC Helgason and CDC Trey had a significantly higher ($P < 0.05$) fractional rate of degradation (Kd) of CP compared to the other cultivars. Despite this only CDC Cowboy had a higher ($P < 0.05$) effective degradability of CP with a value of 74.1 g/kg DM in comparison to a mean of 63.7 g/kg DM for all the other cultivars. There were no differences in the rumen degradation parameters of starch except for Kd. The lowest ($P < 0.05$) value of 0.118 /h was observed for CDC Dolly and the highest ($P < 0.050$) value of 0.334 /h for CDC Cowboy with a mean value of 0.225 /h for the other cultivars. Total digestible nutrient (TDN) values ranged from 809 to 854 g/kg DM with CDC Cowboy, CDC Helgason and CDC Trey having a higher ($P < 0.050$) TDN than AC Metcalfe whereas, Mcleod was significantly lower ($P < 0.05$). Generally, CDC Cowboy, CDC Helgason and CDC Trey had a significantly higher ($P < 0.05$) estimated energy values for both dairy and beef cattle compared to AC Metcalfe. Metabolisable protein (MP) was significantly higher ($P < 0.05$) in CDC Cowboy in comparison to AC Metcalfe. Cultivars CDC Helgason and Mcleod had a significantly lower MP compared to AC Metcalfe. In conclusion, CDC Cowboy had the most favourable predicted energy and metabolisable protein supply of all the cultivars studied and theoretically increased animal performance.

Project Details

Abbreviations: ADF, acid detergent fibre; ADIP, acid detergent insoluble protein; ADL, acid detergent lignin; AECP, truly absorbed endogenous protein; AMCP, truly absorbed microbial crude protein; ARUP, truly absorbed rumen undegradable protein; CA, fraction of carbohydrate that is fermentable sugar; CB1, fraction of carbohydrate that is starch and pectin;

CB2, fraction of the carbohydrate that is available cell wall; CC, fraction of carbohydrate that is unfermentable cell wall; CDC, Crop Development Center; CHO, carbohydrate; CP, crude protein; DM, dry matter; D, insoluble but potentially degradable fraction from in sacco residues; DE_{3x}, digestible energy at 3x maintenance for dairy cattle; ECP, endogenous rumen protein; ED effective degradability of DM, CP and starch (EDDM, EDCP, EDST); EE, ether extract; Kd, fractional rate of degradation of the D fraction from in sacco incubations; Kr, fractional rumen outflow rate; MCP_{EDCP}, microbial protein synthesised in the rumen based on EDCP; MCP_{TDN}, microbial protein synthesised in the rumen based on discounted TDN; ME, metabolisable energy for beef cattle; ME_{3x}, metabolisable energy at 3x maintenance for dairy cattle; ME_g, metabolisable energy for growth in beef cattle; ME_m, metabolisable energy for maintenance for beef cattle; MP, metabolisable protein; NE_{L3x}, net energy for lactation at 3x maintenance of dairy cattle; NDF, neutral detergent fibre; NDIP, neutral detergent insoluble protein; NPN, non protein nitrogen; NSC, non structural carbohydrates; RU, rumen undegradable dry matter, protein and starch (RUDM, RUP, RUST); S, soluble fraction of the in sacco incubations; SCP, soluble crude protein; TDN, total digestible nutrients estimated from NRC (2001).

Introduction

Barley (*Hordeum vulgare*) is extensively grown in the Northern US and Western Canada due to a short growing season and unfavourable climatic conditions for corn (*Zea mays* L.) production (Lewandrowski and Schimmelpfennig, 1999). Canada has the world's largest area of barley but is only the second largest producer (Kim and Dale, 2004) because of reduced yields (2.6 Mg dried grain/ha) attributable to climate and soil fertility (Lewandrowski and Schimmelpfennig, 1999). Production of AC Metcalfe (a two rowed, malting type barley) during 2006 was 419,000 Mg which accounted for approximately 60% of all malting barley grown in Canada (CGC, 2007) and this cultivar has superseded cultivar Harrington in terms of superior malting characteristics. During the 2005-2006 season 749,000 Mg malting barley was sold to domestic processors for use as animal feed or for use as seed (AAFC, 2007). Malting varieties of barley are characterized by their rapid germination and

mobilization of starches to sugars, typically 99% of malting barley germinates within 3 d (CGC, 2007). Inclusion of rapidly degradable starch into ruminant diets is a major precursor for the onset of acidosis (Owens et al., 1998). However, feed varieties tend to have slower rumen degradation rates and an increased amount of rumen un-degradable starch (Yu et al., 2003). This may be advantageous in terms of milk yield as starch digested post ruminally is utilized more efficiently for milk fat synthesis (Nocek and Tamminga,. 1991). Grings et al. (1992) and Yang et al. (1997) have shown that corn can be replaced by barley in the diets of high yielding dairy cattle without affecting yield or milk composition. Current barley breeding programs are focused on increasing grain yield, disease resistance and decreasing the amount of lodging. Additionally, barley cultivars are being developed for low input and high environmental stress conditions.

Objective

The aims of this study are to examine the differences in chemical composition, protein and carbohydrate fractions, *in situ* degradation characteristics, predicted energy and protein supply and degraded protein balance, metabolizable protein and microbial protein synthesis of five cultivars of spring sown barley in relation to AC Metcalfe

Materials and Methods

Barley Genotype Samples Collected at Three Consecutive Years

Six, two row cultivars (*cv.*) of spring sown hulled barley, *cv.* AC Metcalfe (Brandon Research Center, Agriculture and Agri-food Canada, Brandon, MB, Canada), CDC Cowboy, CDC Dolly, CDC Helgason, CDC Trey (Crop Development Center (CDC), University of Saskatchewan, Saskatoon, SK, Canada) and McLeod (WestBred, LLC, Bozeman, MT, USA) were grown, without irrigation, at a field site close to Saskatoon, SK, Canada for three cor ecutive years commencing in 2003. Sub-samples of grain collected at harvest were pro ided by the CDC, University of Saskatchewan.

Sample Preparation and Barley Processing

Barley samples (~60 g) were milled to pass through a 1 mm screen (Christy Norris 8" laboratory mill, Ipswich, UK) and a sub-sample (~2 g) was further milled to pass through a 0.5 mm screen (Retsch ZM-100, Brinkmann Instruments Ltd., Ontario, Canada). Milled samples were stored in air tight vials at room temperature prior to subsequent analysis. Approximately 500 g of each barley sample was processed through a roller mill (Economill, Sven Products, Apollo Machine and Products Ltd., Saskatoon, SK, Canada) with a roller gap width set at 1.12 mm.

In situ Rumen Degradation Parameters

Animals and Experimental Diets

Three, mature, dry Canadian Holstein dairy cows fitted with permanent rumen cannular (10 cm internal diameter, Bar Diamond, ID, USA) were used for the determination of the *in situ* rumen degradation parameters. The cows were housed individually in pens of approximately 4 × 4 m at the University of Saskatchewan research farm. Cows were fed 50:50 forage to concentrate ratio on a DM basis at 10 g/kg body weight in two equal portions at 08:00 and 16:00 h daily. The diet comprised of whole crop barley silage (DM 605 g/kg, CP 140 g/kg DM, NDF 504 g/kg DM, ADF 325 g/kg DM) and a standard, barley based, dairy concentrate (CP 380 g/kg DM; Federated Cooperatives Ltd., Saskatoon, SK, Canada). Cows had free access to fresh clean drinking water and were bedded on barley straw three times weekly. The animals used in this experiment were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993).

Rumen Incubation

Approximately 8 g rolled barley was accurately weighed into a pre-weighed, numbered, nylon bag with a pore size of 43 µm. The bags were sealed by folding the neck of the bag over approximately 2 cm from the top and secured using an elastic band resulting in a sample size to bag surface area of 31.7 mg/cm^2. Bags were incubated for 2, 4, 8, 12, 24 and 48 h using a complete exchange design (Paine et al., 1982). At each time point one bag from each sample replicate (n=18) was placed into a mesh laundry bag along with a 0.5 kg weight and placed in the ventral rumen. After incubation, the laundry bag was removed and another

inserted in its place. Upon removal the bags were place in approximately 10 l cold water to remove excess ruminal contents and stop microbial activity prior to being stored at -20°C. All samples were incubated in duplicate within each cow. Zero hour bags were treated identically to the post ruminally incubated bags. Upon completion of all the rumen incubations, all of the frozen bags were defrosted slowly at 4°C and were then washed by hand in cold tap water. The bags were washed until the water ran clean. Washed bags were dried in a forced draught oven at 65°C for 48 h. Elastic bands were removed from each bag and the bags reweighed. Bag residues were pooled for each time point within each cow and were milled to pass through a 0.5 mm screen (Retsch ZM-100, Brinkmann Instruments Ltd., Ontario, Canada).

Chemical Analysis

All analyses were carried out on samples milled to pass through a 1 mm screen unless otherwise stated. Dry matter (DM) and ash was determined by drying the samples to a constant weight at 135°C (AOAC 930.15) followed by dry ignition at 550°C for 24 h (MAFF, 1986). Ether extract (EE) was determined by refluxing samples in the presence of ethoxyethane for 6 h (AOAC 954.02). Crude protein (CP) was determined using the Kjeldahl method (AOAC 984.13) using an auto-titrator (Kjeltic 1030, FOSS Teactor, Sweeden). *In situ* residues were analysed for nitrogen by the Dumas method (AOAC 993.03) using a Leco FP 528 analyser (Leco Corporation, St. Joseph, MI, USA). Starch was determined on the 0.5 mm milled samples by the method of McCleary *et al.* (1997). Neutral detergent fibre (aNDF) was determined in beakers using the method of Robertson and Van Soest (1980) with a heat stable α-amylase (Termamyl 120; A3402, Sigma Aldrich, Canada). Sodium sulphite was omitted. Acid detergent fibre (ADF) was determined in beakers by the method of Van Soest *et al.* (1991). All other reagents for aNDF and ADF were as described by Van Soest *et al.* (1991). Residues of aNDF and ADF were filtered through a filter paper (11 cm #54; Whatman, Whatman Plc., Middlesex, UK) and subsequently analysed for neutral detergent insoluble protein (NDIP) and acid detergent insoluble protein (ADIP) respectively using the Kjeldahl method as described by Licitra *et al.* (1996). Acid detergent lignin (ADL; Van Soest and Robertson, 1980) was determined using 26 N sulphuric acid following extraction with acid detergent solution using fibre bags (ANKOM Technology, Fairport, New York, USA). Non

protein nitrogen (NPN) and soluble CP (SCP) were determined using the Kjeldahl method following extraction with sodium tungstate solution and borate phosphate buffer solution respectively as described by Licitra *et al.* (1996).

The NLIN Modeling and Calculations

Non structural carbohydrates (NSC) were calculated according to Van Soest *et al.* (1991) and carbohydrate (CHO) was calculated according to Sniffen *et al.* (1992). Total digestible nutrients (TDN; NRC, 2001), digestible energy for production (DE), metabolisable energy for production (ME) and net energy for lactation (NE_L) were calculated at 3x maintenance for dairy cattle (NRC, 2001). Additionally, ME, NE for maintenance (NE_m) and NE for growth (NE_g) for beef cattle (NRC, 1996) were calculated based upon chemical composition. Protein and carbohydrate sub-fractions were calculated according to the Cornell Net Carbohydrate and Protein System (CNCPS; Sniffen *et al.*, 1992). Data from the *in situ* degradation studies were fitted to the model of Ørskov and McDonald (1979); $P = S + D \times (1\text{-}\exp^{(-kd \times t)})$ using the NLIN procedure of SAS (1999). Where P is the degradability of DM, CP or starch at time t, S is the immediately soluble fraction, D the degradable fraction and k_d is the fractional rate of degradation of fraction D. Effective degradability (ED) was calculated as described by Ørskov and McDonald (1979); $ED = S + \{(D \times Kd)/(Kd + Kr)\}$. Where S, D and Kd are the same as previously described and Kr is the assumed rumen outflow rate for concentrates set at 0.06 /h (Tamminga et al., 1994).

Statistical Analysis

Chemical composition, CNCPS and NRC data was fitted to the model $y_{ij} = \mu + \alpha_i + \beta_j + \varepsilon_{ij}$ using the MIXED procedure of SAS (1999). Where y_{ij} is the measured variable, μ the overall mean, α the effect of cultivar (i = 1 to 6), β the fixed blocking effect of year (j = 1 to 3) and ε_{ij} is the associated error. Data from the *in situ* experiment was fitted to the model $y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \varepsilon_{ijk}$ using the MIXED procedure of SAS (1999). Where y_{ijk} is the measured variable, μ, α and β are the same as stated previously, γ the random blocking effect of cow (k = 1 to 3) and ε_{ikj} is the associated error. Statistical differences were declared at $P \leq 0.05$. Treatment means were separated using Fishers LSD at 0.05.

Results and Discussion

Results

Chemical Composition

The proximate analyses of the six different barley cultivars are shown in Table 1. All varieties had similar DM, CP, ADL SCP, NPN, NDIP and ADIP content with mean values of 945.3 g/kg, 121.4, 27.5 g/kg DM, 192.2, 58.7, 61.3 and 4.8 g/kg CP respectively. Despite the significant difference ($P < 0.05$) in ash concentration of the barley cultivars this difference was considered practically insignificant with a mean value of 24.9 g/kg DM. There was no statistical difference in EE concentration between AC Metcalfe and all cultivars except CDC Helgason which had a significantly higher ($P < 0.05$) EE concentration of 25.0 g/kg DM compared to a mean value of 18.5 g/kg DM for the other five cultivars. There was no statistical difference between AC Metcalfe and any of the other cultivars in terms of calculated CHO with an overall mean of 834.0 g/kg DM. The calculated NSC concentration of CDC Cowboy, CDC Helgason and CDC Trey were significantly ($P < 0.05$) higher than that of the other cultivars. Starch concentrations ranged from 491.5 to 536.6 g/kg DM with CDC Cowboy, CDC Trey and Mcleod having a significantly ($P < 0.05$) higher starch concentration compared to AC Metcalfe. The aNDF and ADF contents were both significantly ($P < 0.05$) effected by both cultivar with mean values of 157 and 50 g/kg DM for aNDF and ADF respectively.

Protein and Carbohydrate Fractions

The protein and carbohydrate fractions partitioned using the CNCPS are shown in Table 2. There was no difference between any of the cultivars in terms of protein fractions PA (the NPN), PB1 (rapidly degradable CP), PB2 (intermediately soluble CP), PB3 (slowly degradable CP) or PC (bound CP) with means of 58.7, 133.5, 724.2, 78.9 and 4.8 g/kg CP respectively. There was a significant difference between cultivars in terms of CA (immediately soluble sugars), CB1 (soluble starch and pectin) and CB2 (soluble fibre), but there was no difference in terms of CC (unavailable fibre) with a mean value of 68.3 g/kg

CHO. The CA fraction ranged from 154.1 to 244.1 g/kg CHO. Mcleod had the lowest ($P < 0.05$) CA value and CDC Helgason had the highest ($P < 0.05$) CA value compared to AC Metcalfe. The CB1 fraction ranged from 589.1 to 643.5 g/kg CHO with CDC Dolly, Mcleod and CDC Trey having a higher ($P < 0.05$) CB1 fraction compared to AC Metcalfe. The CB2 fraction ranged from 59.4 to 132.8 g/kg CHO with there being no difference between AC Metcalfe, CDC Cowboy, CDC Dolly and CDC Trey. However, Mcleod had a lower ($P < 0.05$) CB2 fraction compared to AC Metcalfe whereas CDC Helgason had a higher ($P < 0.05$) CB2 fraction compared to AC Metcalfe.

In situ Rumen Degradation Characteristics/Kinetics

The *in situ* rumen DM, CP and starch degradation characteristics of the six different barley cultivars using Orskov and Tamminga' kinetics models are presented in Tables 3 and 4, respectively. The results show that there were significant differences ($P < 0.05$) in all measured DM parameters. Cultivars CDC Dolly, Mcleod and CDC Helgason had significantly ($P < 0.05$) lower S fractions compared to AC Metcalfe with no differences between the other cultivars. CDC Cowboy had a significantly ($P < 0.05$) lower and CDC Dolly had a significantly ($P < 0.05$) higher B fraction in comparison to the other cultivars. The Kd value for CDC Dolly (0.141 /h) was significantly ($P < 0.05$) lower than that of AC Metcalfe (0.165 /h) whereas, the Kd value for CDC Cowboy (0.217 /h) was significantly higher ($P < 0.05$). The other cultivars were comparable to that of AC Metcalfe. The results indicate that in comparison to AC Metcalfe cultivars CDC Dolly and CDC Helgason are more ($P < 0.050$) extensively degraded within the rumen whereas, CDC Cowboy is the least ($P < 0.05$) extensively degraded.

There was no difference in the S fraction of CP with a mean value of 19.2 g/kg CP. Cultivars CDC Cowboy and CDC Helgason had significantly ($P < 0.05$) lower D fractions than AC Metcalfe with values of 800.6, 795.2 and 840.9 g/kg CP respectively. The other cultivars did not differ significantly from AC Metcalfe. AC Metcalfe and CDC Dolly had the slowest Kd value of 0.088 /h. All other cultivars, except Mcleod had a significantly ($P < 0.05$) higher Kd than AC Metcalfe with a maximum value of 0.127 /h being observed. The amount of RUP on a g/kg CP basis was significantly ($P < 0.05$) highest in AC Metcalf, CDC Dolly, CDC

Helgason and CDC Trey and lowest ($P < 0.05$) in CDC Cowboy with an intermediate value for Mcleod. There was no difference in RUP on a DM basis with a mean value of 56.0 g/kg DM. The EDCP on a g/kg CP basis was comparable between AC Metcalfe, CDC Dolly, CDC Helgason and Mcleod with the highest values being observed in CDC Cowboy and CDC Trey. Whereas, on a DM basis CDC Cowboy had the highest ($P < 0.05$) value compared to all other varieties.

In respect to starch degradation there were no differences between cultivars observed in terms of S, D, EDST or RUST with mean values of 197.1, 718.4, 777.4 and 222.6 g/kg starch respectively. There was a significant ($P < 0.05$) difference in Kd for starch with CDC Dolly having the slowest (0.118 /h), CDC Cowboy having the fastest (0.334 /h) and intermediate rates for the other cultivars.

Predicted Energy Values Using Using NRC-2001 Summary Approach

The predicted energy values for dairy and beef cattle of the six different barley cultivars are presented in Table 5. The predicted TDN values ranged from 808.7 to 854.1 g/kg DM and were significantly ($P < 0.05$) different. In comparison to AC Metcalfe cultivar Mcleod had the lowest ($P < 0.05$) TDN whereas, CDC Trey and CDC Helgason had the highest ($P < 0.05$) with intermediate values for the other cultivars. There were significant differences ($P < 0.05$) between all the predicted energy values for both dairy cattle and beef cattle. In general Mcleod had the lowest energy concentration and CDC Helgason had the highest. The control cultivar, AC Metcalfe, was typically the second lowest variety. The mean values for dairy cattle (NRC, 2001) were 14.04, 12.30 and 7.85 MJ/kg DM for DE_{3x}, ME_{3x} and NE_{L3x} respectively and the mean values for beef cattle (NRC, 1996) were 12.54, 8.49 and 5.73 MJ/kg DM for ME, ME_m and NE_g respectively.

Predicted Protein Supply, Degraded Protein Balance, Microbial Protein Synthesis

The predicted protein values for dairy cattle of the six different barley cultivars are presented in Table 6. Despite the significant differences observed there was no difference between the control cultivar AC Metcalf and any other barley cultivar in respect to the potential microbial CP (MCP) with a mean value of 55.61 g/kg DM. There was a significant

difference ($P < 0.05$) between all cultivars and AC Metcalfe in the amount of potential MCP supplied based on discounted TDN. Mcleod was significantly lower ($P < 0.05$) than AC Metcalfe with all other cultivars being significantly higher ($P < 0.05$) with CDC Trey having the highest MCP based on discounted TDN. The amount of truly absorbed MCP in the small intestine (AMCP) was greatest ($P < 0.05$) in CDC Cowboy (40.31 g/kg DM) with no difference being observed between any of the other cultivars (mean 34.64 g/kg DM). There was no difference between cultivars in terms of truly absorbed RUP (ARUP) with a mean value of 47.62 g/kg DM. Despite the significant ($P < 0.05$) differences reported here for endogenous CP (ECP) and truly absorbed ECP in the small intestine (AECP) the values were considered practically insignificant with mean values of 11.23 and 4.49 g/kg DM respectively. Total metabolisable protein (MP) ranged from 85.44 to 92.32 g/kg DM with CDC Cowboy having the highest ($P < 0.05$) and Mcleod having the lowest ($P < 0.05$) value.

Discussion

Chemical Composition, Protein and Carbohydrate Fractions

These results are comparable to other North American and Canadian barley cultivars reported by Fregeau-Reid et al. (2001), NRC (2001) and Yu et al. (2003) in terms of DM, ash, CP and EE. The higher EE result reported here for CDC Helgason may also explain the higher predicted energy values for this cultivar due to the large amount of energy attributable to EE concentration (Weiss et al., 1992). The major differences between the current results and those reported by NRC (2001) and Yu et al. (2003) are in terms of the fibre fractions and the associated fibre bound protein fractions. The fibre and fibre associated protein fractions reported here are lower (approximately 100 and 150 g/kg DM for NDF and ADF respectively and approximately 80 and 35 g/kg CP for NDIP and ADIP respectively) than those reported by NRC (2001) and Yu et al. (2003). These differences may be attributable to variations in fibre methodologies. Lictra et al. (1996) published standardized methodologies for nitrogen fractionation of feedstuffs and included brief details on the fibre methods using specific laboratory equipment. However, there are many different adaptations for fibre methods based upon type of feedstuff analysed, enzyme used and type of equipment available. Therefore, it

is essential that these are detailed fully so that suitable comparisons can be made. The starch contents of barley can vary largely with a range of 483 to 625 g/kg DM reported by Khorasani et al. (2000). The values reported here fall within the lower third of this range. However, they contain between 50-90 g/kg DM more starch than that reported by Yu et al. (2003) for the malting type barley cultivar Harrington. The increased starch content of the cultivars assed here has also resulted in higher predicted energy content of these cultivars compared to Harrington (DE_{3x} 13.77 MJ/kg DM; Yu et al., 3003) and a higher CB1 fraction. Approximately 741 g/kg NSC was starch for all cultivars except for Mcleod, which had a higher value of 802 g/kg NSC. This indicates that Mcleod contains less soluble sugars and pectin (CA fraction) than the other cultivars (NRC, 2001). This observation is comparable to the feed type cultivar Valier analysed by Yu et al. (2003) and as such may reduce acid load within the rumen in comparison to the other cultivars analysed here. The CNCPS protein fractions determined in this study were comparable to the PA and PB1 fractions reported by Yu et al. (2003) however, there were differences in the amounts of PB2, PB3 and PC fractions. The PC fraction is the same as the ADIP value and as such the differences have already been discussed. In this current study more of the protein was intermediately degradable (mean 724 g/kg CP) and less of the protein was slowly degradable (mean 79 g/kg CP) in comparison to the results of Yu et al. (2003), who reported mean values of 529 and 264 g/kg CP for PB2 and PB3 respectively. Further differences were noted when examining the carbohydrate fractions. The results of this study were comparable to that of Harrington reported by Yu et al. (2003) in respect to the immediately soluble carbohydrate fraction but largely different from the result of 86 g/kg CHO reported for Valier. This large difference between all the cultivars and Valier is surprising since there was little difference in the starch and CHO fractions reported by Yu et al. (2003), but the predicted NSC content of Valier was lower. This large variation may again be attributable to the differences in NDF, ADF, NDIN and ADIN methodologies since they are used in the calculation of CA, CB1, CB2, CC, PB2 and PB3. Overall, there was little difference between AC Metcalfe and any of the other cultivars in respect to their chemical composition.

In situ Rumen Degradation Characteristics/Kinetics

Huntington and Givens (1995) concluded that comparisons between studies are complicated due to the large differences observed between methods of sample preparation, effect of basal diet and the variation observed intra- and inter- animal. Yu et al. (2003) demonstrated that the *in situ* degradation parameters of barley grain were heavily influenced by processing methods, with less differences being observed with milled samples in comparison to rolled ones. In this study, there were few differences observed between the malting cultivar AC Metcalfe and the rumen undegradable of DM, CP and starch on a DM basis except fo CDC Cowboy which had the greatest proportion of RUDM, although this had no further ef ct on any of the undegradable fractions. There was no difference in the amount of total deg. dable DM or starch (S+D) between any of the cultivars analysed here but AC Metcalfe, CDC olly and CDC Trey had higher total degradable CP compared to the other cultivars. Yu et al. (2003) reported large differences between a malting and a feed type cultivar with the malting type ha ing a significantly higher S (57 vs. 24 g/kg CP) and D (843 vs. 694 g/kg CP) fractions for CP b no difference in Kd (mean 0.116 /h) which resulted in a higher EDCP for the malting type (81 vs. 62 g/kg DM). Results from this study do not support this observation since AC Metcalfe had similar CP degradation characteristics to all other cultivars except for CDC Cowboy which had the highest EDCP. The extent of starch disappearance recorded for Mcleod was contradictory to the predicted CHO fractions where it was predicted to have the lowest soluble CHO fraction and here no difference was observed. The CNCPS fractions were determined on milled products whereas the *in situ* values were determined using rolled samples. It is plausible to suggest that these differences in sample preparation might have caused this due to the sample matrix being destroyed to a greater extent by milling. The starch Kd values reported here are typically higher than that of 0.13 /h reported by Ortega-Cerrilla et al. (1999). This large difference between starch Kd values was unexpected and may be indicative of a different starch and protein matrix within the grain structure of these different cultivars (Yu et al., 2004). If the cultivars of barley analysed here were utilised in ruminant rations the diets would have to be evaluated carefully to match the rapidly degradable starch with a rapidly degradable protein supply, in order to maximise microbial nitrogen capture and reduce acid load in the rumen.

Predicted Energy Protein Supply

The predicted TDN values are comparable to the tabular value of 827 g/kg DM for rolled barley (NRC, 2001). The value of 854.1 g/kg DM reported here for CDC Helgason is comparable to the tabular value of 850 g/kg DM for dry cracked corn on the other hand it is lower than that of 866 g/kg DM for rolled wheat (NRC, 2001). Therefore, CDC Helgason may be used to replace dry rolled corn. Corn is typically steam/heat processed and this increases the TDN value (NRC, 2001). However, it is unclear whether the same is true when barley grains are steam/heat processed and as such further investigation is warranted. The energy values presented here are comparable to those reported by NRC (2001) but lower than those reported by NRC (1996). This was due to the assumed degradation characteristics being utilised by NRC (2001) whereas, NRC (1996) predicts TDN based on actual measurements of CP Kd (Weiss et al., 1992). CDC Cowboy, CDC Helgason and CDC Trey had energy values that were consistently higher than that of AC Metcalf. Whereas, the energy values for Mcleod were consistently lower than AC Metcalfe. The mean energy values reported here were on average 0.3 MJ/kg DM higher than those reported by Yu et al. (2003) making these cultivars more attractive in terms of nutritive quality. The potential microbial CP (MCP) supply was limited by the amount of EDCP and not by TDN an effect also noted by Yu et al. (2003). Therefore, there was no difference between AC Metcalfe and any of the other cultivars in terms of MCP supplied. The mean MP in this study was 88 g/kg DM which was less than the mean result of 101 g/kg DM reported by Yu et al. (2003) this was due to the difference in relative amounts of MCP and RUP supplied between studies. Overall, CDC Cowboy offered the greatest post ruminal protein supply along with a higher energy value compared to AC Metcalf.

Conclusion

From the results of this study it was concluded that there was limited differences between the control cultivar, AC Metcalfe, and CDC Dolly, CDC Helgason and CDC Trey. Mcleod tended to have the lowest nutritive value, predicted energy values and predicted MP supply. Whereas, CDC Cowboy tended to have a comparable chemical composition but a

more extensive rumen degradation rate and a higher predicted energy and MP supply compared to the other cultivars analysed in this study. Further work is required in order to asses the differences between cultivars in terms of actual animal performance and their effect on rumen function. The data reported here will assist end users of these varieties in terms of maximising animal production when diets are formulated using the NRC (1996; 2001) approach.

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Tables

Table 1. Detailed chemical composition of different barley cultivars

	Cultivar							Significance	
	AC Metcalfe	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	all cultivars	Feed vs. milling[§]
Chemical composition (g kg^{-1} DM unless stated otherwise)									
DM g kg^{-1}	943.4	941.8	946.7	945.7	947.9	946.5	2.37	0.500	0.393
Ash	23.9^{a}	25.8^{b}	24.3^{a}	25.0^{ab}	24.4^{a}	25.9^{b}	0.36	0.013	0.015
EE	20.4^{ab}	16.9^{ab}	18.2^{ab}	25.3^{c}	20.9^{b}	16.2^{a}	1.41	0.010	0.592
CP	121.4	130.0	120.6	117.7	120.8	118.0	2.61	0.069	0.987
CHO	834.3^{abc}	827.2^{a}	836.9^{bc}	832.0^{ab}	833.9^{abc}	839.9^{c}	2.37	0.050	0.892
NSC	662.0^{a}	703.0^{b}	666.7^{a}	713.0^{bc}	722.7^{c}	655.1^{a}	4.28	<0.001	<0.001
Starch	491.5^{a}	520.9^{bc}	508.4^{ab}	510.0^{ab}	536.6^{c}	525.7^{bc}	7.49	0.022	0.006
ADF	46.4^{b}	49.4^{bc}	39.8^{a}	51.8^{c}	49.1^{bc}	65.9^{d}	1.64	<0.001	0.023
aNDF	183.0^{bc}	134.5^{a}	179.9^{b}	129.7^{a}	121.9^{a}	193.4^{c}	4.03	<0.001	<0.001
ADL	29.0	31.2	25.5	23.5	25.2	30.5	2.51	0.245	0.531
SCP g kg^{-1} CP	188.7	198.8	170.9	203.7	205.5	185.4	9.05	0.147	0.682
NPN g kg^{-1} CP	51.7	76.7	70.5	40.8	58.2	54.3	16.72	0.694	0.654
NDIP g kg^{-1} CP	88.0	10.3	81.2	91.2	88.3	8.6	9.70	0.051	0.138
ADIP g kg^{-1} CP	8.4	1.9	1.0	3.8	10.3	3.2	9.70	0.075	0.098

[§] Contrast between AC Metcalf and mean of all other cultivars. Means within rows not sharing a common superscript letter differ significantly ($P < 0.050$)

For definitions please see list of abbreviations.

Table 2. Cornell Net Carbohydrate Protein system (CNCPS) fractions of different barley cultivars

	Cultivar							Significance	
	AC Metcalfe	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	All cultivars	Feed-type vs. Malting-type[§]
CNCPS protein fractions (g kg^{-1} CP)									
PA	51.7	76.7	70.5	40.8	58.2	54.3	16.72	0.694	0.654
PB1	137.0	122.1	100.4	162.9	147.3	131.1	17.60	0.277	0.831
PB2	723.4	721.1	747.9	705.1	706.2	741.2	10.16	0.065	0.935
PB	79.6	78.2	80.1	87.4	78.0	70.2	3.70	0.131	0.850
PC	8.4	1.9	1.0	3.8	10.3	3.2	2.21	0.075	0.100
CNCPS carbohydrate fractions (g kg^{-1} CHO)									
CA	204.3^{bc}	220.0^{cd}	189.1^{b}	244.1^{d}	223.2^{cd}	154.1^{a}	9.70	0.001	0.872
CB1	589.1^{a}	630.0^{bc}	607.6^{ab}	613.0^{ab}	643.5^{c}	625.9^{bc}	8.85	0.019	0.005
CB2	123.0^{b}	59.4^{a}	130.1^{b}	75.2^{a}	60.7^{a}	132.8^{b}	10.82	0.001	0.025
CC	83.5	90.6	73.2	67.8	7.26	87.2	7.23	0.242	0.525

[§] Contrast between AC Metcalf and mean of all other cultivars. Means within rows not sharing a common superscript letter differ significantly ($P < 0.050$)

For definitions please see list of abbreviations.

Table 3. *In situ* rumen DM and CP degradation characteristics of different barley cultivars, using Orskov first order kinetic model

	Cultivar							Significance	
	AC Metcalfe	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	all cultivars	Feed-type vs. Malting-type[§]
In sacco rumen DM degradation characteristics (g kg^{-1} DM unless otherwise stated)									
S	96.5^{b}	101.8^{b}	69.6^{a}	78.0^{a}	94.6^{b}	71.9^{a}	3.97	<0.001	<0.001
D	721.4^{b}	697.1^{a}	750.2^{c}	722.1^{b}	724.8^{b}	723.7^{b}	9.08	<0.001	0.511
Kd h^{-1}	0.165^{bc}	0.217^{d}	0.141^{a}	0.157^{ab}	0.178^{c}	0.174^{bc}	0.0116	<0.001	0.160
RUDM[†]	624.8^{bc}	644.6^{d}	594.2^{a}	599.0^{a}	634.8^{cd}	609.3^{ab}	10.91	<0.001	0.159
EDDM[†]	375.2^{bc}	355.4^{a}	405.8^{d}	401.0^{d}	365.2^{ab}	390.7^{cd}	10.91	<0.001	0.159
In sacco rumen CP degradation characteristics (g kg^{-1} CP unless otherwise stated)									
S	23.3	26.8	17.5	14.4	17.1	15.9	10.41	0.955	0.416
D	840.9^{b}	800.6^{a}	850.1^{b}	795.2^{a}	830.2^{ab}	828.1^{ab}	13.83	0.020	0.498
Kd h^{-1}	0.088^{a}	0.127^{c}	0.088^{a}	0.111^{bc}	0.113^{bc}	0.102^{ab}	0.0605	<0.001	0.024
RUCP[†]	482.2^{c}	432.5^{a}	478.2^{c}	472.9^{c}	446.3^{ab}	466.0^{bc}	13.80	0.001	0.350
RUCP[†] g kg^{-1} DM	58.2	55.9	57.6	55.7	53.9	54.8	1.73	0.110	0.508
EDCP[†]	517.8^{a}	567.5^{c}	521.8^{a}	527.1^{a}	553.7^{bc}	534.0^{ab}	13.80	0.001	0.350
EDCP[†] g kg^{-1} DM	63.2^{ab}	74.1^{c}	63.0^{a}	62.2^{a}	66.9^{b}	63.1^{ab}	1.82	<0.001	0.284

[§] Contrast between AC Metcalf and mean of all other cultivars. [†] Calculated at a rumen outflow rate of 0.06 h^{-1}. Means within rows not sharing a common superscript letter differ significantly ($P < 0.050$). For definitions please see list of abbreviations.

Table 4. *In situ* rumen starch degradation characteristics of different barley cultivars, using Tamminga's starch model in DVE/OEB (1994)

	Cultivar							Significance	
	AC Metcalfe	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	all cultivars	Feed-type vs. Malting-type[§]
In sacco rumen starch degradation characteristics (g kg^{-1} starch unless otherwise stated)									
S	235.8	199.4	209.6	148.3	187.3	202.2	26.58	0.334	0.259
D	682.5	714.7	718.9	749.5	732.1	712.5	27.38	0.609	0.370
Kd h^{-1}	0.240[b]	0.334[c]	0.118[a]	0.242[b]	0.269[b]	0.270[b]	0.0200	<0.001	0.038
RUST[†]	258.0	233.0	227.3	173.0	214.8	229.2	25.40	0.313	0.703
RUST[†] g kg^{-1} DM	128.6	116.1	113.3	86.2	107.1	114.3	12.66	0.313	0.284
EDST[†]	742.0	767.0	772.7	827.0	785.2	770.8	25.40	0.313	0.703
EDST[†] g kg^{-1} DM	369.8	382.3	385.1	412.2	391.3	384.1	12.66	0.313	<0.001

[§] Contrast between AC Metcalf and mean of all other cultivars.

[†] Calculated at a rumen outflow rate of 0.06 h^{-1}. Means within rows not sharing a common superscript letter differ significantly ($P < 0.050$). For definitions please see list of abbreviations.

Table 5. Predicted energy to beef and dairy cattle of different barley cultivars of barley. Values in parenthesis are Mcal/kg DM

	Cultivar							
	AC Metcalfe	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*
Truly digestible fractions								
tdNFC (%DM)	67.47^{a}	71.65^{b}	67.95^{a}	72.67^{bc}	73.66^{c}	66.77^{a}	0.436	<0.001
tdCP (%DM)	11.70^{a}	12.88^{b}	12.00^{a}	11.56^{a}	11.46^{a}	11.59^{a}	0.232	0.013
tdFA (%DM)	1.04^{ab}	0.69^{ab}	0.82^{ab}	1.53^{c}	1.09^{b}	0.62^{a}	0.141	0.010
tdNDF (%DM)	7.49^{b}	4.29^{a}	7.79^{b}	4.73^{a}	4.07^{a}	8.11^{b}	0.463	<0.001
TDN g/kg DM	819.9^{b}	833.9^{c}	825.8^{bc}	854.1^{d}	846.5^{d}	808.7^{a}	3.36	<0.001
Predicted energy values for dairy cattle[†] (MJ/kg DM; NRC, 2001)								
DE_{3x}	13.84^{b}	14.12^{cd}	13.97^{bc}	14.39^{e}	14.26^{cd}	13.65^{a}	0.059	<0.001
(in Mcal/kg DM)	(3.31)	(3.37)	(3.34)	(3.44)	(3.41)	(3.26)		
ME_{3x}	12.09^{ab}	12.41^{c}	12.21^{b}	12.66^{d}	12.52^{cd}	11.92^{a}	0.058	<0.001
(in Mcal/kg DM)	(2.89)	(2.96)	(2.92)	(3.02)	(2.99)	(2.85)		
NE_{L3x}	7.70^{ab}	7.91^{cd}	7.80^{bc}	8.09^{e}	8.01^{cd}	7.58^{a}	0.041	<0.001
(in Mcal/kg DM)	(1.84)	(1.89)	(1.86)	(1.93)	(1.91)	(1.81)		
Predicted energy values for beef cattle (MJ/kg DM; NRC, 1996)								
ME	12.35^{ab}	12.63^{c}	12.46^{b}	12.84^{d}	12.74^{cd}	12.20^{a}	0.050	<0.001
(in Mcal/kg DM)	(2.95)	(3.02)	(2.98)	(3.07)	(3.04)	(2.91)		
ME_{m}	8.33^{ab}	8.56^{cd}	8.43^{bc}	8.75^{e}	8.64^{de}	8.21^{a}	0.043	<0.001
(in Mcal/kg DM)	(1.99)	(2.04)	(2.01)	(2.09)	(2.06)	(1.96)		
ME_{g}	5.61^{b}	5.79^{c}	5.68^{b}	5.96^{d}	5.88^{cd}	5.48^{a}	0.035	<0.001
(in Mcal/kg DM)	(1.34)	(1.38)	(1.36)	(1.42)	(1.40)	(1.31)		

Means within rows not sharing a common superscript letter differ significantly ($P < 0.05$)

Table 6. Predicted protein supply to beef and dairy cattle of different barley cultivars of barley. Values in parenthesis are Mcal/kg DM

	Cultivar							
	AC Metcalfe	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*
Predicted protein supply for dairy cattle (g/kg DM; NRC, 2001)								
MCP_{EDCP}	53.70^{ab}	62.99^{b}	53.55^{a}	52.89^{a}	56.84^{b}	53.67^{ab}	1.543	<0.001
MCP_{TDN}	97.84^{b}	99.51^{d}	98.55^{c}	101.93^{f}	101.03^{e}	96.51^{a}	0.187	<0.001
$MCP_{Supplied}$	53.70^{ab}	62.99^{b}	53.55^{a}	52.89^{a}	56.84^{b}	53.67^{ab}	1.543	<0.001
AMCP	34.37^{ab}	40.31^{c}	34.27^{a}	33.85^{a}	36.38^{b}	34.35^{ab}	0.988	<0.001
RUP	58.19	55.92	57.62	55.70	53.86	54.81	1.732	0.110
ARUP	49.47	47.53	48.98	47.34	45.78	46.59	1.472	0.110
ECP	11.20^{ab}	11.18^{a}	11.24^{bc}	11.23^{bc}	11.26^{c}	11.24^{bc}	0.013	0.002
AECP	4.48^{ab}	4.47^{a}	4.50^{bc}	4.49^{bc}	4.50^{c}	4.49^{bc}	0.006	0.008
MP	88.32^{b}	92.32^{c}	87.75^{ab}	85.68^{a}	86.66^{ab}	85.44^{a}	0.903	<0.001

Means within rows not sharing a common superscript letter differ significantly ($P < 0.050$)

Project 2: An Investigation of Carbohydrate and Protein Degradation Ratios, Nitrogen to Energy Synchronization, and Hourly Effective Rumen Digestion of Barley: Effect of Variety and Growth Year

This project was extracted from a peer-reviewed article published in the Journal of Animal Physiology and Animal Nutrition (Peiqiang Yu, K.J. Kenton and L. Du. 2009, *In Press*). It was extracted the following two studies:

Study 5. Effects of genotypes collected at three consecutive years on carbohydrate and protein degradation ratios, nitrogen to energy synchronization (completed)

Study 6. Effects of genotypes collected at three consecutive years on hourly effective rumen digestion of barley (*Effect of variety and growth year*) (completed)

Project Summary

The objective of this study was to investigate rumen available soluble, insoluble and total protein (CP), estimated structural (SC) and non-structural carbohydrate (starch: ST), degradation characteristic ratios, and hourly effective degradation of six barley varieties during three consecutive growth years (2003, 2004, 2005). The magnitude of the differences was determined between the varieties and growth years. Measured degradation kinetics included soluble fraction (S), undegradable fraction (U), lag time (T0) and rate of degradation (Kd) of the insoluble but degradable fraction (D). Rumen available soluble, insoluble, and total N, structural and non-structural carbohydrate and the rumen degradation characteristic ratios were determined using the Tamminga Rumen Degradation Ratio System. Characteristics of the hourly effective degradation between N and carbohydrate (CHO) among the six barley varieties and three years were also studied. The degradation ratios included: (1) total rumen available N and carbohydrate ratio (FN/FCHO), rumen available soluble N and carbohydrate ratio (SN/SCHO), and rumen available insoluble N and carbohydrate ratio (EN/ECHO). Results show that both the barley variety and growth year

had a significant effect on degradation kinetics (S, D, U, T0, and/or Kd). Differences in the ratio of FN/FCHO among varieties ranged from 16.6 to 19.0 g/kg ($P<0.01$). There was no difference in SN/SCHO ($P>0.05$) with an average of 4.9 g/kg. The difference in the EN/ECHO ratio tended to be significant among the varieties ($P=0.069$) ranging from 18.4 to 21.3 g/kg. Differences in the hourly effective degradation between N and CHO were relatively small at shorter incubation times (2 to 4 hours) However, as the length of rumen incubation increased (12 to 24 hours), much larger differences in the rate of effective hourly degradation were observed. In conclusion, both barley variety and growth year had significant effects on rumen degradation kinetics. The mean FN/FCHO ratio of 17.2 (range 16.6 to 19.0) was observed for the six barley varieties in this experiment. All barley varieties exhibited a less optimal rumen fermentation ratio (17.2 < optimum: FN/FCHO = 25 to 33 g N per kg CHO)

Project Details

Abbreviations

ADF: Acid detergent fiber

ADL: Acid detergent lignin

ADIN: Acid detergent insoluble N

CHO: Carbohydrates

CP: Crude protein

D: Potentially degradable fraction

DM: Dry matter

ECHO: Insoluble rumen available carbohydrate (CHO) (ECHO = ESC + EST)

EE: Ether extract (crude fat)

EN: Insoluble rumen available N

ESC: Insoluble rumen available structural carbohydrate (SC)

EST: Insoluble rumen available non-structural carbohydrate (ST)

FSC: Total rumen available estimated SC

FST: Total rumen available ST

Kd: Degradation rate

Kp: Passage rate

NDF: Neutral detergent fiber

NDIN: Neutral detergent insoluble nitrogen

NFC: Non-fibre carbohydrates

NPN: Non-protein nitrogen

PD Potentially degradable insoluble fraction (CP, starch, or estimated structural CHO)

Ratio EN/ECHO: Ratio of insoluble rumen available N/Insoluble rumen available carbohydrate;

Ratio FN/FCHO: Ratio total rumen available N/ Total rumen available carbohydrates

Ratio SN/SCHO: Ratio soluble rumen N / Soluble rumen carbohydrates

Ratio TN/TCHO: Ratio between total N and total carbohydrates

S: Soluble fraction

SCHO: Soluble rumen carbohydrates (CHO) [SCHO = SSC + SST]

SCP: Soluble crude protein

SN: Soluble rumen N

SST: Soluble non-structural carbohydrates;

U: Undegradable fraction

Introduction

In Canada there are about 50 varieties of commercially available barley, 10 of which account for almost 90% of total barley seeded acreage. So far, two hundred varieties of locally adapted barley have been registered and cultivated in Canada (CFIA, 2007). Of the total Canadian barley production, approximately 20% goes to the malting industry and the remaining 80% enters the livestock feed market. Barley has an attractive energy and protein content compared to corn in cattle (Khorasani et al., 2000). It is high in starch (Yang et al., 1997a; 1997b) with an A-type X-ray pattern (Robyt, 1998), and contains higher levels of lysine, methionine, tryptophan, and cystine than corn (Pond et al. 1995). Barley usually has a

high degradation rate and a high effective degradability of starch (>800 g/kg) (Nocek and Tamminga, 1991).

In western Canada, barley is the primary constituent of concentrate rations for both dairy and beef cattle. In a typical finishing beef cattle diet, barley can be included at up to 85-90% of total ration. Therefore, synchronization of nitrogen and energy supplied by barley is important for optimizing microbial growth in the rumen. Many efforts have been made in order to optimize the use of barley grain in cattle diets (Gibson et al., 1994; Mathison, 1996; Yang et al., 1997a, b; Yang et al., 2000). However, little research has been conducted to systematically determine the magnitude of the differences in the digestive kinetics of each component (such as structural carbohydrate, non-structural carbohydrate, and protein). To our knowledge, no research has been conducted to determine degradation characteristic ratios and hourly effective degradation affected by barley variety and growth year.

As we know, each component of a feed has its own pattern of rumen degradation characteristics (Tamminga et al., 1990). Knowledge of the rumen availability of each component is important because microbial protein synthesis in the rumen is highly related to the availability of each feed component in the rumen. In modern feed formulation, the degradation characteristic ratios can be used to optimize the composition of dairy diets (Tamminga et al. 1990; 1994). Unfortunately, there is limited data on degradation characteristic ratios reported in research papers studying the rumen degradation characteristics of a feed.

Objective

The objective of this study was to investigate the effect of variety and growth year on (1) rumen degradation kinetics, rumen available soluble, insoluble and total protein (CP), structural (SC) and non-structural carbohydrate (starch: ST), (2) rumen degradation characteristic ratios, and (3) hourly effective degradation between N and CHO of six barley varieties during three consecutive growth years (2003, 2004, 2005) in western Canada in order to determine the magnitude of the differences between barley varieties and growth year. The use of rumen degradation ratios may help in formulating diets with an optimal

composition for rumen fermentation. The ratios studied in this experiment were: (1) the ratio between total available N and total available carbohydrates (FN/FCHO), (2) the ratio between total soluble N and total soluble carbohydrates (SN/SCHO), and (3) the ratio between total insoluble N and total insoluble carbohydrates (EN/ECHO). These ratios were compared with the optimum ratios, which are: 25~33 g/kg FN/FCHO (Czerkawski 1986; Tamminga et al. 1990).

Materials and Methods

Barley Varieties, Types and Growth Condition

Six, two-row varieties of spring sown barley [AC Metcalfe (Brandon Research Center, Agriculture and Agri-Food Canada, Brandon, MB, Canada), CDC Cowboy, CDC Dolly, CDC Helgason, CDC Trey (Crop Development Center, University of Saskatchewan, Saskatoon) and McLeod (WestBred, LLC, Bozeman, MT, USA)] were grown, without irrigation, at the Kernen Crop Research Farm, University of Saskatchewan, Saskatoon, SK, Canada for three consecutive years commencing in 2003, 2004 and 2005. All the barleys were managed using the same and standard agronomic production practices for all barley production. Sub-samples of grain collected at harvest were provided by the Crop Development Center (Brian Rossnagel), University of Saskatchewan. The detailed information on barley types (feed-type or malting type) and growth climate condition: highest mean temperature and rainfall during the three consecutive years are presented in Table 1.

Animal and Diets

Three non-lactating and non-pregnant Holstein-Friesian cows, fitted with rumen cannulas (internal diameter of 10 cm), were used for measuring rumen degradation of barley varieties. Cows were housed in individual pens in the dairy experimental station at the University of Saskatchewan (Saskatoon, Canada), and fed a ration that met dairy cow maintenance requirements (NRC 2001) twice daily at 0800 h and 1600 h. Each cow received daily 15-kg TMR, consisting of 27.5% pelleted concentrate [containing 55.8% barley, 11.7% soybean meal, 10.3% canola meal, 5% oats, 4.1% wheat, 3.3% wheat distillers dried grains,

3% mineral-vitamin mix, 2.2% corn gluten meal, 2.1% molasses, 0.7% canola oil, 0.6% cobalt-iodized salt, 0.6% sodium bicarbonate, 0.3% dynamite (International Minerals and Chemicals Corp., Mundelein, IL, USA), 0.05% niacin-magnesium mix, and 0.05% ground limestone], 55% barley silage, 12.5% alfalfa hay, and 5% dehydrated alfalfa. Water was always available. Cows were allowed free access to outdoor exercise pens. The animals used in the experiment were cared for in accordance with the guidelines of the Canadian Council on Animal Care (1993).

Barley Processing Method

All barley samples were coarsely processed using a roller mill with a roller gap of 1.12 mm (Economill, Sven Products, Apollo Machine and Products Ltd., Saskatoon, SK, Canada) at the College of Engineering, University of Saskatchewan, Canada.

In Situ Rumen Incubation at Various Times

Ruminal degradation kinetics were determined using a standard Departmental in situ procedure (Yu et al., 2003). Number-coded nylon bags (10×20 cm) with a pore size of ca. 40 μm (ScreenTech Corp, Canada) were used for incubating samples in the rumen. These bags were tied about 2 cm below the top, to obtain a ratio of sample size to bag surface area of approximately 28 mg/cm^2. The rumen incubations were performed according to the 'gradual addition/all out' schedule (the bags were inserted sequentially and retrieved at the same time). Samples were incubated for 48, 24, 12, 8, 4, and 2 hours. After incubation, the bags were removed from the rumen and rinsed under a cold stream of tap water to remove excess ruminal contents and to stop microbial activity. The bags were hand-washed in cool water without detergent and then dried at 55°C for 48 h. The 0 h incubation samples were only washed and dried under the same conditions. Residues were pooled according to treatments and incubation times and then ground through a 1-mm screen (Retsch ZM-1, Brinkmann Instruments LTD, Ontario) for chemical analysis (AOAC, 1990).

Ørskov and Tamminga's Models for Rumen Degradation Kinetics

Rumen degradation characteristics were determined as described by the first order

kinetics degradation model of Ørskov and McDonald (1979), and modified by Robinson et al. (1986) and Tamminga et al. (1994). The parameters studies were the soluble fraction (S) which was washed out with water at 0 h without rumen incubation, the undegradable fraction (U), the insoluble fraction (D) which was degraded exponentially, the degradation rate (Kd, %/h) and lag time (T0, h). The results were calculated using the NLIN (non linear) procedure of the statistical package SAS (2003) using iterative least squares regression (Gauss-Newton method) by the following the first order kinetics equations:

Non-structural carbohydrates ST: $R(t) = (100 - S) \times e^{-Kd \times t}$

Estimated structural carbohydrate SC: $R(t) = U + (100 - U) \times e^{-Kd \times (t - T0)}$

Crude protein CP: $R(t) = U + (100 - S - U) \times e^{-Kd \times (t-T0)}$

where, R(t) = residue (%) of the amount of incubated material after time t (h) of rumen incubation.

Rumen Degradation Ratios System

The ratios of rumen available carbohydrate to available protein and the degradation of carbohydrate to protein should be optimum and synchronised to achieve efficient microbial growth and minimize N loss in the rumen. This can be expressed in part by FN/FCHO, EN/ECHO and SN/SCHO ratios (Tamminga et al. 1990). The abbreviations we used here are originally from the degradation ratio system reported by Tamminga et al. (1990). The rumen degradation characteristic ratios can be used to formulate diets that meet the requirements for optimum rumen fermentation. Based on the measured characteristics, the rumen degradation characteristic ratios were calculated by the following the formulas (Tamminga et al. 1990):

1) EN/ECHO (g/kg) = Insoluble rumen available N/Insoluble rumen available carbohydrate

2) SN/SCHO (g/kg) = Soluble rumen N / Soluble rumen carbohydrates

3) FN/FCHO (g/kg) = Total rumen available N/ Total rumen available carbohydrates

Hourly Effective Degradation of N and Energy and Their Hourly Ratio

Based on available degradation kinetics, the hourly effective degradation was estimated as $ED = S + D \times Kd / (Kd + Kp) \times (1 - \exp^{-t(Kd + kp)})$, according to Sinclair et al

(1993). The passage rate, Kp, was assumed at 6%/h (Tamminga et al., 2004). The difference in cumulative amounts degraded between successive incubation times was regarded as the amount of degraded in that time period.

Chemical Analysis

All analyses were carried out on samples milled to pass through a 1 mm screen unless otherwise stated. Dry matter (DM) and ash was determined by drying the samples to a constant weight at 135°C (AOAC 930.15) followed by dry ignition at 550°C for 24 h (MAFF, 1986). Ether extract (EE) was determined by refluxing samples in the presence of ethoxyethane for 6 h (AOAC 954.02). Crude protein (CP) was determined using the Kjeldahl method (AOAC 984.13) using an auto-titrator (Kjeltic 1030, FOSS Teactor, Sweeden). In situ residues were analysed for N by the Dumas method (AOAC 993.03) using a Leco FP 528 analyser (Leco Corporation, St. Joseph, MI, USA). Starch was determined on 0.5 mm milled samples by the method of McCleary et al. (1997). Neutral detergent fibre (aNDF) was determined in beakers using the method of Van Soest et al. (1991) with a heat stable α-amylase (Termamyl 120; A3402, Sigma Aldrich, Canada). Sodium sulphite was omitted. Acid detergent fibre (ADF) was determined in beakers by the method of Van Soest et al. (1991). All other reagents used for aNDF and ADF are described by Van Soest et al. (1991). Residues of aNDF and ADF were filtered through a filter paper (11 cm #54; Whatman, Whatman Plc., Middlesex, UK) and subsequently analysed for neutral detergent insoluble protein (NDIP) and acid detergent insoluble protein (ADIP) using the Kjeldahl method as described by Licitra et al. (1996). Acid detergent lignin (ADL) was determined using 26 N sulphuric acid following extraction with acid detergent solution using fibre bags (ANKOM Technology, Fairport, New York, USA). Non protein nitrogen (NPN) and soluble CP (SCP) were determined using the Kjeldahl method following extraction with sodium tungstate solution and borate phosphate buffer solution respectively as described by Licitra et al. (1996).

Statistical Analysis

Statistical analyses were performed with SAS (2003). For chemical compositions and

protein and carbohydrate fractions, the data was analysed using a Mixed procedure with the model $y_{ij}=\mu + \alpha_i + \beta_j + \varepsilon_{ij}$, where y_{ij} is the measured variable, μ the overall mean, α_i the effect of cultivar (i = 1 to 6), β_j the effect of year (j = 1 to 3) and ε_{ij} is the associated error. For in situ kinetics and degradation ratio, the data were analysed using a Mixed procedure with the model: $y_{ijk}=\mu + \alpha_i + \beta_j + \gamma_k + \varepsilon_{ijk}$, where y_{ijk} is the measured variable, μ, α_i and β_j are the same as stated previously, γ_k the random blocking effect of cow (k = 1 to 3) and ε_{ikj} is the associated error. Fisher's Protected LSD test was used for treatment comparisons. Significance was declared at $P < 0.05$.

Results and Discussion

The Magnitude of Differences in Chemical Profile

Proximate analysis results of the six barley varieties are shown in Table 2. Barley varieties had similar DM, CP, ADL, SCP, NPN, NDIP and ADIP content with mean values of 945.3 g/kg, 121.4, 27.5 g/kg DM, 192.2, 58.7, 61.3 and 4.8 g/kg CP, respectively. The mean value of ash concentration was 24.9 g/kg DM, and a significant difference ($P<0.05$) in ash content was detected among the six barley samples. The EE concentration was similar ($P>0.05$) for all cultivars except CDC Helgason which had a significantly higher ($P<0.05$) EE concentration of 25.0 g/kg DM compared to a mean value of 18.5 g/kg DM for the other five cultivars. The mean calculated CHO content of the six cultivars was 834.0 g/kg DM, and there were no observed difference between AC Metcalfe and any of the other varieties. The calculated NFC concentration (which was calculated by subtracting aNDF corrected for NDIP from CHO) of CDC Cowboy, CDC Helgason and CDC Trey were significantly ($P<0.05$) higher than that of the other cultivars. Starch concentration ranged from 491.5 to 536.6 g/kg DM with CDC Cowboy, CDC Trey and Mcleod having a significantly ($P<0.05$) higher starch concentration compared to AC Metcalfe. Significant differences ($P<0.05$) for both aNDF (mean 157 g/kg DM) and ADF (mean 50 g/kg DM) were observed between barley varieties.

These results are comparable to other North American and Canadian barley analyses reported by Fregeau-Reid et al. (2001), NRC (2001) and Yu et al. (2003) in terms of DM, ash,

CP and EE. The major differences between the current results and those reported by NRC (2001) and Yu et al. (2003) are in terms of the fibre fractions and the associated fibre-bound protein fractions. The fibre (ADF and NDF) and fibre-associated protein (NDIP and ADIP) fractions reported here are lower (approximately 100 and 150 g/kg DM for NDF and ADF respectively and approximately 80 and 35 g/kg CP for NDIP and ADIP, respectively) than those reported by NRC (2001) and Yu et al. (2003). These differences may be attributed to variations in the methodology used for fibre determination. Lictra et al. (1996) published standardized methods for N fractionation of feedstuffs and included brief details on the fibre methods using specific laboratory equipment. However, there are many different adaptations for fibre methods based upon type of feedstuff analysed, enzyme used and type of equipment available. Therefore, it is essential that these parameters are specified so that suitable comparisons can be made. The starch content of barley can be variable. Khorasani et al. (2000) reported a range in barley starch content of 483 to 625 g/kg DM. The values reported here fall within this range. However, they contain between 50-90 g/kg DM more starch than that reported by Yu et al. (2003) for the malting-type cultivar, Harrington.

The Magnitude of Differences in Rumen Degradation Residues between Barley Varieties and between Growth Years

In situ rumen residues of DM and CP at 0, 2, 4, 8, 12, 24 and 48 hour incubation times for six barley varieties and three growth years are presented in Table 3. Previous study (Yu et al., 2003) showed that the percent of rumen residue was highly dependent on processing method. In this study, barley seeds were rolled into 2 to 4 parts according to commercial feed barley processing practice. In general, the barley variety and growth year significantly affected ($P<0.05$) rumen disappearance at most incubation times (Table 3). The difference in DM rumen residue at a single incubation time ranged from 2.5 to 8.3% (at 4 h) between the barley varieties and from 0.7 (at 0h) to 4.7% (at 4 h) between the growth years (2003, 2004 and 2005). The magnitude of difference in CP rumen residue was much higher than that of DM rumen residue (Figures 1: a vs. b), ranging from 4.2 to 10.5% between barley varieties and from 1.2 to 8.2% between growth years (Figure 2). These observations indicated that when comparing barley samples from different growth years, the magnitude of the relative

differences in rumen DM and CP residue increases with increasing rumen incubation time (Figure 1 and 2).

In situ rumen residues of estimated structural and non-structural carbohydrate (ST, SC) for six barley varieties and three growth years at incubation times of 0, 2, 4, 8, 12, 24 and 48 h are presented in Table 4. It was observed that both barley variety and growth year had an effect on rumen ST and SC residue at various incubation times (Table 4). However, the magnitude of difference between ST residue and SC residue among barley varieties was different (Figure 1: c vs. d) with the variation in SC rumen degradation (8.0 to 12.2%) being much higher than that of ST (2.4 to 13.2%). Growth year also had an effect on ST and SC degradation (Figure 2: .c vs.d). The difference in ST degradation between the growth years ranged from 3.3 to 9.5% and from 0.9 to 16.7% for SC (Table 4). The difference in rumen residue between the varieties may be associated with chemical composition profiles and barley genotype. Differences observed in amount of rumen residue between growth years may be associated with variation in weather and growing conditions which are discussed below. It needs to be mentioned that most of the component would be digested or passed at these later times, thus the impact would be relatively small.

The Magnitude of Differences in Rumen Available Soluble, Insoluble and Total Protein and Protein Degradation Kinetics between Barley Varieties and Growth Years

The effects of variety and growth year on protein degradation kinetics of barley are presented in Table 5. Significant differences were observed for rumen degradation kinetics both among barley varieties and growth years. Among barley varieties, differences in D (79 to 84% CP) and U (13 to 30% CP) CP fractions and the degradation rate Kd (8.8 to 13.7%/h) were significant ($P<0.01$), but differences were not observed ($P>0.05$) in the soluble fraction, S (average: 1.9%), or lag time (T0: 0.32 h). The largest differences in D, U and Kd between the barley varieties was 6.0% CP, 6.3 %CP and 3.8%/h, respectively. Growth year also had significant effects on CP fractions D and U, and on and Kd ($P<0.05$), but no effect on S and T0 (Table 5). It should be noted that the degradation kinetics were also influenced by processing method depending on whether coarse (Roller miller) or fine processing was used (Yu et al. (2003). The gap size of a roller miller also affected the degradation characteristics.

The effects of variety and growth year on rumen available soluble (SN), insoluble (EN) and total rumen available protein (FN) are also presented in Table 5. Among barley varieties, there was significant variation in the potentially degradable insoluble protein (PD) (range: 93 to 104 g/kg DM), rumen available insoluble protein (EN) (range: 9 to 11 g/kg DM), and total rumen available nitrogen (FN) (range: 10 to 12 g/kg DM). Rumen available soluble nitrogen (SN) ranged from 0.3 to 0.6 g/kg DM and was not different ($P>0.05$) among barley varieties. Growth year also had significant effects ($P<0.01$) on PD, EN, FN. The greatest difference in mean values among growth years was 13, 2, 2 g/kg DM for PD, EN, FN, respectively. Growth year did not have a significant effect ($P>0.05$) on SN. To our knowledge, no reports have been found in the literature regarding rumen available soluble, insoluble and total protein, therefore, no comparisons can be made to the results reported here.

The Magnitude of Differences in Rumen Available Soluble, Insoluble and Total Non-Structural Carbohydrate (ST) and Degradation Kinetics between Barley Varieties and Growth Years

The effects of variety and growth year on the degradation kinetics, rumen available soluble, insoluble and total rumen available non-structural carbohydrate of barley are presented in Table 6. Total starch content in the six barley varieties ranged from 491 to 526 g/kg DM (Table 2). The rate of rumen degradation, Kd, for the six barley varieties ranged from12 to 21 %/h and differed significantly ($P<0.01$) among varieties. Conversely, no differences ($P>0.05$) were observed for the S (average: 19.7% ST) and D (80.3% ST) fractions. The largest difference in ST content and Kd between barley varieties was 28 g/kg DM and 7.2 %/h, respectively. Growth year had a significant effect on total ST content, S and D fractions ($P<0.01$), and Kd ($P=0.07$) of barley (Table 6).

Based on the degradation kinetics, rumen available soluble (SST), insoluble (EST) and total rumen available non-structural (FST) carbohydrates were estimated in Table 6. Significant differences ($P<0.01$) were observed between barley varieties for potentially degradable (PD) insoluble ST (range: 376 to 436 g/kg DM), rumen available insoluble ST (EST) (range: 264 to 324 g/kg DM), and total rumen available ST (FST) (range: 374 to 427

g/kg DM). However, there was no observed difference (P>0.05) in rumen available soluble ST (SST) (mean: 102 g/kg DM). Growth year had a significant effect (P<0.01) on SST and FST, but no significant effect (P>0.05) on PD and EST. There have been no reports found in the literature on rumen available soluble, insoluble and total non-structural carbohydrates, therefore, comparisons to the data in this experiment cannot be made.

The Magnitude of Differences in Rumen Available Insoluble and Total Estimated Structural Carbohydrate and Degradation Kinetics between Barley Varieties and Growth Years

The effects of variety and growth year on the degradation kinetics of the estimated structural carbohydrate of barley are presented in Table 7. The structural carbohydrate (SC) of the six barley varieties varied significantly and ranged from 349 to 387 g/kg DM of this structural carbohydrate, the D and U fractions tended to be significantly different (P=0.0527) and ranged from 62 to 68 % SC and 33 to 38% SC, respectively. No differences were observed in T0 or Kd of SC. Growth year had a significant effect on total SC and T0 (P<0.01), but not on the D and U fractions or Kd (P>0.05) (Table 7).

It can be seen from Table 7 that both variety and growth year had significant effects (P<0.05) on potentially degradable insoluble (PD), rumen available insoluble (ESC) and total rumen available (FSC) fraction of SC in barley. PD, ESC, and FSC ranged from 218 to 261 g/kg DM, 193 to 230 g/kg DM and 191 to 230 g/kg DM, respectively. The magnitude of differences between the varieties was greater than the differences between growth years. The range in PD, ESC and FSC between barley varieties was 43, 37 and 39 g/kg DM, respectively, compared to a range of 21, 10 and 19 g/kg DM for PD, ESC, and FSC, respectively, when comparing different growth years. Since there are no reports which have been found in the literature regarding rumen available soluble, insoluble and total structural carbohydrates, it is not possible to make comparisons to the data presented here.

The above results indicate that the growth year had significant effects on available protein, structural and non-structural carbohydrates in barley. This was mainly due to variation in weather conditions during the different growth years. Barley varieties grown in western Canada are usually spring cultivars which are normally seeded during April and May

and harvested during August to September. The weather and environmental conditions during the entire growing season would have an effect on the final barley quality. The six barley varieties studied in this project were all grown at the Kernen Crop Research Farm, University of Saskatchewan, Saskatoon, Canada in 2003, 2004 and 2005. All barley varieties were managed with the same agronomic practices, therefore, weather differences between the three years were considered to be the only factors responsible for growth year effects in the present study. According to weather reports from Environment Canada and Statistics Canada (2003-2005) and field crop reports from Statistics Canada (2003-2005), the highest mean temperature in 2003, 2004 and 2005 was 20.9 °C, 17.3°C and 17.5°C, respectively. Mean rainfalls were 190, 305 and 455 mm in 2003, 2004 and 2005, respectively. Compared to the preceding years, 2003 saw a great improvement in environmental conditions with reduced insect and disease damage, leading to increased barley yield 2003. Compared to 2004 and 2005, the growth season in 2003 was hot and dry with higher mean temperature and lower precipitation. Dry harvest conditions produced good barley seed quality. The 2004 crop year started out with encouraging conditions (warm and moderate precipitation). During the mid-season, there were a series of frosts, but it was not as destructive as previous atrocious weather. On average, 2004 was cooler than the other two years, which encouraged surprisingly high barley production. The level of precipitation in 2004 was intermediate among the three years. Total barley production in 2004 was higher than 2003. The season in 2005 was intermediate in temperature. High levels of precipitation late in the growing season led to wet harvesting conditions and caused problems such as delayed harvesting, high grain moisture, and reduced grain quality. Therefore, the 2005 growth year produced barley of low quality with a significant proportion of moldy and cracked kernels (Du, 2007).

Optimization of Rumen Fermentation and Rumen Degradation Ratios of N to Energy: Effect of Variety and Consecutive Growth Years

For dairy cows, the ratio of total rumen available protein to total rumen available carbohydrate is critical for optimum microbial protein synthesis. Czerkawski (1986) reported that approximately 25 g N per kg rumen available carbohydrate should be sufficient to achieving optimum microbial growth. Tamminga et al. (1990) reported that optimum ratio of

available carbohydrate to protein is approximately 5:1 (approximately 33 g N per kg carbohydrate).

Along with the appropriate ratio of rumen available carbohydrate to protein, synchronization of the rate of carbohydrate and protein degradation is also crucial for efficient microbial growth and minimized loss of rumen N (Tamminga et al., 1994). This relationship can be expressed in part by using FN/FCHO, EN/ECHO and SN/SCHO ratios (Tamming et al., 1990). Based on the measured rumen kinetics (Tables 5-7), various rumen degradation ratios were calculated between the total rumen available N and carbohydrate (FN/FCHO), rumen available soluble N and carbohydrate (SN/SCHO), and rumen available insoluble N and carbohydrate (EN/ECHO) (Table 8) using the Special Degradation Ratio System (Tamminga et al., 1990).

Significant differences between barley varieties were observed for the ratio of FN/FCHO (range: 16.6 to 19.0 g/kg) ($P<0.01$), but not for SN/SCHO ($P>0.10$) (average: 4.9 g/kg). The EN/ECHO ratio tended to differ significantly among the varieties ($P=0.069$) ranging from 18.4 to 21.3 g/kg. Growth year affected ($P<0.01$) FN/FCHO and EN/ECHO which ranged from 15.3 to 18.6 g/kg and 17.0 to 21.4 g/kg, respectively, but no effect on SN/SCHO (average: 4.8 g/kg) was observed (Table 8).

According to the Tamminga Ratio system (Tamminga et al., 1990), the optimum rumen fermentation ratio is estimated at 25 to 30 g N per kg carbohydrate. The results shown here indicate that all barley varieties exhibited a less than optimal rumen fermentation ratio (17.2 < optimum: FN/FCHO = 25 to 33 g N per kg carbohydrates). In order to optimize rumen fermentation, one possible approach would be to improve the degradability characteristics of substrates in the rumen by influencing the fermentation process through specific feeding strategies (selecting more degradable feed ingredients, etc.), or by changing the fermentation process through feed processing (changing physical characteristics of the feed).

The ratio is one of important parameters to check and formulate degradation balance in a diet ration in the modern DVE/OEB diet evaluation and formulation system which was released in 1994 and revised in 2007 (Yu, 2008). In beef finished feedlot diet, it is normal (or common) that feedlot diets contain up to 85-90% barley. This is not the extreme case.

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Tables

Table 1. The variety, type (feed-type or malting-type), row number and growth weather conditions of barley samples

			Growth year		
Barley Varieties[1]	Barley type	Two- or six -row	2003	2004	2005
McLeod	Feed	2	2003	2004	2005
AC Metcalfe	Malting	2	2003	2004	2005
CDC Dolly	Feed	2	2003	2004	2005
CDC Helgason	Feed	2	2003	2004	2005
CDC Trey	Feed	2	2003	2004	2005
CDC Cowboy	Feed (forage)	2	2003	2004	2005
Total samples (18)			6	6	6
			Climate weather condition[2]		
Highest mean Temperature			20.9 °C	17.3 °C	17.5 °C
Rainfall			190 mm	305 mm	455 mm

[1] Original breeder: McLeod: WestBred, LLC, Bozeman, MT, USA; AC Metcalfe: Brandon Research Center, Agriculture and Agri-food Canada, Brandon, MB, Canada; CDC Cowboy, CDC Dolly, CDC Helgason, and CDC Trey: Crop Development Center, University of Saskatchewan, Saskatoon, SK, Canada.

[2] The climate data from Environment Canada and Statistics Canada (2003-2005) and field crop reports from Statistics Canada (2003-2005).

Table 2. Chemical composition and protein and carbohydrate fractions of different barley cultivars

	Varieties						SEM	P value
	AC Metcalfe	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod		
Chemical composition								
DM (g/kg)	943.4	941.8	946.7	945.7	947.9	946.5	2.37	0.500
Ash (g/kg DM)	23.9 ^{a}	25.8^{b}	24.3^{a}	25.0^{ab}	24.4^{a}	25.9^{b}	0.36	0.013
EE (g/kg DM)	20.4 ^{ab}	16.9^{ab}	18.2^{ab}	25.3^{c}	20.9^{b}	16.2^{a}	1.41	0.010
CP (g/kg DM)	121.4	130.0	120.6	117.7	120.8	118.0	2.61	0.069
Starch (g/kg DM)	491.5 ^{a}	520.9^{bc}	508.4^{ab}	510.0^{ab}	536.6^{c}	525.7^{bc}	7.49	0.022
ADF (g/kg DM)	46.4 ^{b}	49.4^{bc}	39.8^{a}	51.8^{c}	49.1^{bc}	65.9^{d}	1.64	<0.001
aNDF (g/kg DM)	183.0 ^{bc}	134.5^{a}	179.9^{b}	129.7^{a}	121.9^{a}	193.4^{c}	4.03	<0.001
ADL (g/kg DM)	29.0	31.2	25.5	23.5	25.2	30.5	2.51	0.245
SCP (g/kg CP)	188.7	198.8	170.9	203.7	205.5	185.4	9.05	0.147
NPN (g/kg CP)	51.7	76.7	70.5	40.8	58.2	54.3	16.72	0.694
NDIP (g/kg CP)	88.0	10.3	81.2	91.2	88.3	8.6	9.70	0.051
ADIP (g/kg CP)	8.4	1.9	1.0	3.8	10.3	3.2	9.70	0.075

SEM = Standard error of the means. Treatment comparisons were done by using the Fisher's Protected LSD test. Significance was declared at $P < 0.05$.

Table 3. Comparison of 6 barley varieties[1] growth in western Canada for three consecutive growth years (2003, 2004 and 2005) in in situ rumen residue of dry matter (DM) and crude protein (CP) determined using three rumen fistulated dairy cattle (total samples: n = 6 barley varieties × 3 years =18 samples)

Items		Barley variety						Year				P value	
	MeLeod	AC Metcalfe	CDC Dolly	CDC Helgason	CDC Trey	CDC Cowboy	SEM[2]	2003	2004	2005	SEM	Variety	Year
In situ rumen residue (%) of dry matter (DM)													
R0h	92.8 a	90.3 b	93.0 a	92.3 a	90.5 b	89.8 b	0.41	91.5	91.8	91.1	0.31	<0.0001	0.2008
R2h	68.8 b	66.0 bc	72.6 a	71.6 a	66.0 c	62.8 d	1.69	70.7 a	67.4 b	66.5 b	1.62	<0.0001	<0.0001
R4h	53.8 bc	52.6 c	56.7 a	55.8 ab	51.7 c	48.4 d	1.82	56.2 a	51.5 b	51.8 b	1.68	<0.0001	<0.0001
R8h	39.0 ab	37.3 bc	41.3 a	40.1 a	35.7 cd	34.2 d	1.20	40.4 a	36.7 b	36.6 b	1.04	<0.0001	<0.0001
R12h	34.9 bc	33.7 bc	38.4 a	35.7 ab	32.2 cd	30.5 d	1.32	36.7 a	33.2 b	32.9 b	1.13	<0.0001	0.0003
R24h	24.0 ab	23.5 ab	23.4 ab	25.0 a	22.1 b	22.6 b	1.50	25.7 a	22.0 b	22.6 b	1.37	0.1885	<0.0001
R48h	15.3 a	12.2 c	13.6 bc	15.5 a	12.6 c	14.7 ab	0.68	16.6 a	11.9 c	13.6 b	0.58	<0.0001	<0.0001
In situ rumen residue (%) of crude protein (CP)													
R0h	102.2	98.0	99.6	101.5	101.8	99.3	1.92	102.1	99.9	99.2	1.40	0.5312	0.2865
R2h	88.0 b	89.7 ab	93.5 a	90.1 ab	83.0 c	86.6 bc	2.03	89.8 a	88.6 a	87.1 a	1.71	0.0007	0.2272
R4h	73.4 a	69.5 bc	72.2 ab	71.4 ab	67.0 cd	65.6 d	1.36	74.8 a	67.4 b	67.3 b	1.11	<0.0001	<0.0001
R8h	52.5 abc	52.1 bc	55.8 a	54.4 ab	49.9 cd	48.4 d	1.44	56.7 a	50.9 b	49.0 b	1.13	0.0016	<0.0001
R12h	46.4 ab	48.7 ab	49.1 a	46.3 ab	44.6 bc	41.8 c	1.56	51.0 a	44.7 b	42.8 b	1.10	0.0189	<0.0001
R24h	26.4 ab	28.5 a	25.8 ab	28.8 a	25.9 ab	24.6 b	2.11	30.4 a	24.6 b	25.1 b	1.97	0.0537	<0.0001
R48h	14.9 ab	12.6 b	13.6 b	17.5 a	12.4 b	14.6 b	1.12	17.9 a	17.9 a	11.3 b	13.5 b	0.0077	<0.0001

[1] Barley samples were coarsely dry-rolled in a grain roller mill (Sven Grain Mill, Apollo Machine and Products Ltd., Saskatoon, Canada) with a roller gap of 1.12 mm.

[2] SEM = Standard error of the means. Treatment comparisons were used Fisher's Protected LSD test. Significance was declared at $P < 0.05$.

Table 4. Comparison of 6 barley varieties[1] growth in western Canada for three consecutive growth years (2003, 2004 and 2005) in in situ rumen residue of estimated non-structural carbohydrate (ST) and estimated structural carbohydrate (SC) determined using three rumen fistulated dairy cattle (total samples: n = 6 barley varieties × 3 years =18 samples)

Items	MeLeod	Barley variety					SEM[2]	Year			SEM	P value	
		AC Metcalfe	CDC Dolly	CDC Helgason	CDC Trey	CDC Cowboy		2003	2004	2005		Variety	Year
In situ rumen residue (%) of estimated non-structural carbohydrate (ST)													
R0h	79.8	76.4	79.0	83.2	81.3	80.1	2.61	85.7 a	76.4 b	77.8 b	1.85	0.5922	0.0018
R2h	50.1 bc	56.6 a	59.2 a	57.4 a	51.7 b	46.8 c	1.94	58.5 a	50.1 b	53.4 b	1.62	<0.0001	<0.0001
R4h	35.6 bc	38.9 ab	44.6 a	41.1 ab	35.9 bc	31.4 c	3.02	43.8 a	34.3 b	35.6 b	2.54	0.0040	0.0003
R8h	22.4 c	22.9 bc	27.1 a	26.3 ab	20.8 cd	18.1 d	1.61	26.1 a	21.5 b	21.2 b	1.35	<0.0001	0.0004
R12h	17.7 bc	19.3 b	25.0 a	21.1 b	18.3 bc	15.4 c	1.40	22.0 a	18.3 b	18.1 b	1.01	0.0003	0.0117
R24h	8.9 bc	11.6 a	11.0 ab	12.1 a	9.3 bc	8.6 c	1.33	12.2 a	8.7 b	9.9 b	1.21	0.0062	0.0002
R48h	4.4 b	3.2 b	4.0 b	6.0 a	3.2 b	4.2 b	0.58	5.8 a	2.5 c	4.2 b	0.48	0.0024	<0.0001
In situ rumen residue (%) of estimated structural carbohydrate (SC)													
R0h	108.9	102.5	111.7	102.5	101.3	101.6	3.79	95.9 b	112.6 a	107.2 a	2.68	0.2941	0.0002
R2h	90.1 a	74.2 d	85.0 ab	85.6 ab	82.3 bc	77.9 cd	2.72	81.7 b	86.4 a	79.5 b	2.32	<0.0001	0.0060
R4h	74.4	64.8	69.5	71.0	71.1	67.9	3.16	67.5	72.2	69.6	2.51	0.2199	0.2315
R8h	59.1 a	51.1 c	56.4 ab	54.6 bc	54.1 bc	53.2 bc	1.41	54.6	55.3	54.4	1.04	0.0027	0.7756
R12h	56.7 a	47.5 c	53.4 ab	52.3 ab	49.7 bc	49.1 bc	2.34	52.0	51.9	50.5	2.01	0.0051	0.6000
R24h	45.6 a	37.1 c	39.8 bc	41.4 b	40.8 bc	41.4 ab	1.86	42.3	41.5	40.0	1.55	0.0043	0.2953
R48h	31.6 a	23.6 c	26.9 b	27.8 b	27.4 b	30.4 a	1.01	30.1 a	26.5 b	27.1 b	0.84	<0.0001	<0.0001

[1] Barley samples were coarsely dry-rolled in a grain roller mill (Sven Grain Mill, Apollo Machine and Products Ltd., Saskatoon, Canada) with a roller gap of 1.12 mm.

[2] SEM = Standard error of the means. Treatment comparisons were used Fisher's Protected LSD test. Significance was declared at $P < 0.05$.

Table 5. Comparison of 6 barley varieties[1] for three consecutive years (2003, 2004 and 2005) in rumen digestive kinetics and characteristics of crude protein (CP)[2] determined using three rumen fistulated dairy cattle (total samples: n = 6 barley varieties × 3 years =18 samples)

Items	Barley variety						SEM[3]	Year			SEM[3]	P value[4]	
	MeLeod	AC Metcalfe	CDC Dolly	CDC Helgason	CDC Trey	CDC Cowboy		2003	2004	2005		Variety	Year
Protein degradation kinetics													
S (%)	1.59	2.33	1.75	1.44	1.71	2.68	1.041	0.90	2.57	2.28	0.746	0.9545	0.2413
D (%)	82.24 abc	84.06 a	84.83 a	78.81 c	82.45 ab	79.69 bc	1.305	80.45 b	83.91 a	81.67 ab	0.953	0.009	0.0280
U (%)	16.17 bc	13.61 c	13.42 c	19.76 a	15.84 bc	17.63 ab	1.152	18.65 a	13.51 c	16.06 b	0.860	0.0011	0.0001
T0 (h)	0.31 ab	0.24 ab	0.30 ab	0.36 ab	0.11 b	0.57 a	0.148	0.29	0.32	0.33	0.104	0.4092	0.9688
Kd (%/h)	10.15 bc	8.77 c	8.84 c	11.10 ab	11.25 ab	12.67 a	0.605	9.50 b	10.46 ab	11.44 a	0.456	<0.0001	0.0053
Degradation ratio system													
PD[5] (g/kg DM)	97.3 bc	101.9 ab	102.3 ab	93.0 c	99.6 ab	103.7 a	1.82	91.2 b	103.6 a	104.1 a	1.30	0.0013	<0.0001
EN[6] (g/kg DM)	9.6	9.5	9.5	9.4	10.2	10.9	0.29	8.7 b	10.2 a	10.6 a	0.23	0.0009	<0.0001
SN[7] (g/kg DM)	0.3	0.5	0.3	0.3	0.3	0.6	0.21	0.2	0.5	0.5	0.15	0.9108	0.1864
FN[8] (g/kg DM)	10.0 bc	10.1 bc	10.1 bc	9.9 c	10.6 b	11.8 a	0.28	9.0 b	11.0 a	11.3 a	0.23	<0.0001	<0.0001

[1] Barley samples were coarsely dry-rolled in a grain roller mill (Sven Grain Mill, Apollo Machine and Products Ltd., Saskatoon, Canada) with a roller gap of 1.12 mm.

[2] The degradation model of CP: $R(t) = U + (100 - S - U) \times e^{-kd*(t-t0)}$, where, R(t) (%) = residue at time t h, S was the rapidly degradable fraction (%, washable fraction), D is the lowly degradable fraction (D = 100 - S - U, %), Kd was the rate of degradation (%/h) of the D fraction, and T0 (h) was lag time.

[3] SEM = Standard error of the means.

[4] Treatment comparisons were used LSD test. Significance was declared at $P < 0.05$.

[5] PD = Potentially degradable insoluble CP, which was calculated as: PD (g/kg DM) = CP (g/kg DM) × D%, where, D% = 100 - S % - U%.

[6] EN= Rumen available insoluble N.

[7] SN = Rumen available soluble N. [8] FN =Total rumen available N.

Table 6. Comparison of six barley varieties[1] for three consecutive years (2003, 2004 and 2005) growth in western Canada in rumen digestive kinetics and characteristics of non-structure carbohydrate (ST)[2] determined using three rumen fistulated dairy cattle (total samples: n = 6 barley varieties × 3 years =18 samples)

Items	Barley variety						SEM[3]	Year			SEM[3]	P value[4]	
	McLeod	AC Metcalfe	CDC Dolly	CDC Helgason	CDC Trey	CDC Cowboy		2003	2004	2005		Variety	Year
Non-structure carbohydrate (ST) degradation kinetics													
S (%)	20.22 ab	23.58 a	20.96 ab	14.82 b	18.73 ab	19.94 ab	2.657	14.33 b	23.55 a	21.24 a	1.880	0.3343	0.0032
D (%)	79.78 ab	76.42 b	79.04 ab	85.17 a	81.27 ab	80.06 ab	2.657	85.67 a	76.44 b	78.76 b	1.879	0.3343	0.0032
Kd (%/h)	17.45 bc	14.26 d	12.13 d	14.72 cd	17.73 b	21.44 a	1.58	14.86 b	17.26 a	16.74 ab	1.390	<0.0001	0.0656
Degradation ratio system													
PD[5] (g/kg DM)	419.5 a	375.8 b	399.8 ab	433.3 a	435.8 a	416.2 a	12.8	430.8 a	404.9 b	404.5 b	9.05	0.017	0.0724
EST[6] (g/kg DM)	310.5 a	263.5 b	265.6 b	305.3 a	324.0 a	322.6 a	14.18	304.3	295.9	295.6	11.08	0.0014	0.7317
SST[7] (g/kg DM)	106.2	115.7	108.6	76.6	100.8	104.7	13.87	72.5 b	124.9 a	108.9 b	9.81	0.4655	0.0015
FST[8] (g/kg DM	416.7 a	379.2 b	374.2 b	382.0 b	424.8 a	427.3 a	7.71	376.1 c	420.8 a	404.5 b	6.08	<0.0001	<0.0001

[1] Barley samples were coarsely dry-rolled in a grain roller mill (Sven Grain Mill, Apollo Machine and Products Ltd., Saskatoon, Canada) with a roller gap of 1.12 mm.

[2] The degradation model of NSC (ST): $R(t) = (100 - S) \times e^{-kd \cdot t}$, where, R(t) (%) = residue at time t h, S was the rapidly degradable fraction (%, washable fraction), D was the lowly degradable fraction (D = 100 - S (%), Kd was the rate of degradation (%/h) of the D fraction, assuming undegradable fraction U = 0 and no lag time (T0 = 0) in the model.

[3] SEM = Standard error of the means. [4] Treatment comparisons were used LSD test. Significance was declared at $P < 0.05$.

[5] PD = Potentially degradable insoluble ST, which was calculated as: PD (g/kg DM) = ST (g/kg DM) × D%.

[6] EST = Rumen available insoluble ST, which was calculated as: EST = ST × D% × Kd / (Kd + Kp), where, EST and ST in g/kg DM, assuming passage rate of ST Kp = 6%/h.

[7] SST = Rumen available soluble ST, which was calculated as: SST = ST × S%, where, SST and ST in g/kg DM.

[8] FST =Total rumen available ST, which was calculated as: FST = ST × [S% + D% × Kd / (Kd + Kp)], where, FST and ST in g/kg DM, and Kp = 6%/h.

Table 7. Comparison of six barley varieties[1] for three consecutive years (2003, 2004 and 2005) growth in western Canada in rumen digestive kinetics and characteristics of estimated structural carbohydrate (SC)[2] determined using three rumen fistulated dairy cattle (total samples: n = 6 barley varieties × 3 years =18 samples)

Items	Barley variety						SEM[3]	Year			SEM	P value[4]	
	MeLeod	AC Metcalfe	CDC Dolly	CDC Helgason	CDC Trey	CDC Cowboy		2003	2004	2005		Variety	Year
Structural carbohydrate (SC) degradation kinetics													
D' (%)	61.79 c	67.50 a	65.46 abc	67.07 ab	67.19 a	62.51 bc	1.634	64.73	65.48	65.56	1.162	0.0527	0.8535
U (%)	38.21 a	32.50 c	34.54 abc	32.93 bc	32.81 c	37.49 ab	1.634	35.27	34.52	34.44	1.162	0.0527	0.8535
T0 (h)	0.17	0.00	0.20	0.23	0.17	0.23	0.157	0.48 a	0.02 b	0.01 b	0.124	0.8518	0.0014
Kd (%/h)	15.92	20.21	23.96	16.56	14.40	19.74	3.899	20.15	17.10	18.15	2.757	0.5498	0.7305
Degradation ratio system													
PD[5] (g/kg DM)	220.2 c	261.2 a	243.1 ab	249.6 ab	230.4 bc	218.2 c	6.9	248.1 a	227.5 b	235.7 ab	4.88	0.0002	0.0162
ESC[6] (g/kg DM)	186.6 c	230.0 a	210.1 b	204.9 b	193.2 c	189.9 c	5.03	207.0 a	196.6 b	203.8 ab	4.26	<0.0001	0.0258
FSC[7] (g/kg DM)	187.4 c	230.0 a	211.2 b	206.0 b	194.1 c	191.1 c	4.89	209.4 a	196.7 b	203.9 ab	4.05	<0.0001	0.0074

[1] Barley samples were coarsely dry-rolled in a grain roller mill (Sven Grain Mill, Apollo Machine and Products Ltd., Saskatoon, Canada) with a roller gap of 1.12 mm.

[2] The degradation model of SC: $R(t) = U + (100\text{-}U) \times e^{-kd \cdot (t - T0)}$, where, R(t) (%)= residue at time t h, U was the undegradable fraction (%), D was the lowly degradable fraction (D = 100 - U, %), Kd was the rate of degradation (%/h), and T0 was lag time (h).

[3] SEM = Standard error of the means. [4] Treatment comparisons were used LSD test. Significance was declared at $P < 0.05$.

[5] PD = Potentially degradable (insoluble) SC, which was calculated as: PD (g/kg DM) = SC (g/kg DM) × D%

[6] ESC = Rumen available insoluble estimated SC, which was calculated as: ESC = (SC× D% - SC× D% × Kp × T0) × Kd / (Kd + Kp) = SC × D × (100 – Kp × T0) × Kd / (Kd + Kp), where, ESC and SC in g/kg DM, assuming passage rate of structural carbohydrate (cell walls) Kp 2.5%/h.

[7] FSC =Total rumen available estimated SC, which was calculated as FSC = SC × D% × Kd / (Kd + Kp), where, FSC and SC in g/kg DM, assuming Kp = 2.5%/h.

Table 8. Comparison of 6 barley varieties[1] for three consecutive years (2003, 2004 and 2005) growth in western Canada in degradation characteristic ratios between total (FN), soluble (SN) and insoluble rumen available nitrogen (EN) and total (FCHO), soluble (SCHO) and insoluble (ECHO) rumen available carbohydrates determined using three fistulated dairy cows (total samples: n = 6 barley varieties × 3 years =18 samples)

Items	Barley variety						SEM[2]	Year			SEM	P value[3]	
	McLeod	AC Metcalfe	CDC Dolly	CDC Helgason	CDC Trey	CDC Cowboy		2003	2004	2005		Variety	Year
N to CHO ratio in original samples													
TN/TCHO[4] (g/kg)	21.4 c	22.1 b	21.9 bc	21.4 c	22.0 bc	23.9 a	0.25	20.4 c	22.6 b	23.4 a	0.18	<0.0001	<0.0001
Degradation Ratio													
FN/FCHO[5] (g/kg)	16.6 b	16.6 b	17.2 b	16.8 b	17.2 b	19.0 a	0.32	15.3 c	17.7 b	18.6 a	0.24	<0.0001	<0.0001
SN/SCHO[6] (g/kg)	2.5	3.5	8.1	7.2	3.3	4.5	3.63	4.2	3.9	6.4	2.57	0.8531	0.7492
EN/ECHO[7] (g/kg)	19.3 bc	19.4 abc	20.3 ab	18.4 c	19.8 abc	21.3 a	0.66	17.0 b	20.9 a	21.4 a	0.47	0.0691	<0.0001

[1] Barley samples were coarsely dry-rolled in a grain roller mill (Sven Grain Mill, Apollo Machine and Products Ltd., Saskatoon, Canada) with a roller gap of 1.12 mm.

[2] SEM= standard error of the means.

[3] Treatment comparisons were used LSD test. Significance was declared at $P < 0.05$.

[4] TN/TCHO: Ratio between total N and total carbohydrates, where, TCHO = TSC+ TST.

[5] FN/FCHO: Ratio between total available N and total available carbohydrates, where, FCHO = FSC+ FST.

[6] SN/SCHO: Ratio between total soluble N and soluble carbohydrates, where, SCHO = SSC + SST (where SSC=0).

[7] EN/ECHO: Ratio between total insoluble N and insoluble carbohydrates, where ECHO = ESC + EST.

Figures

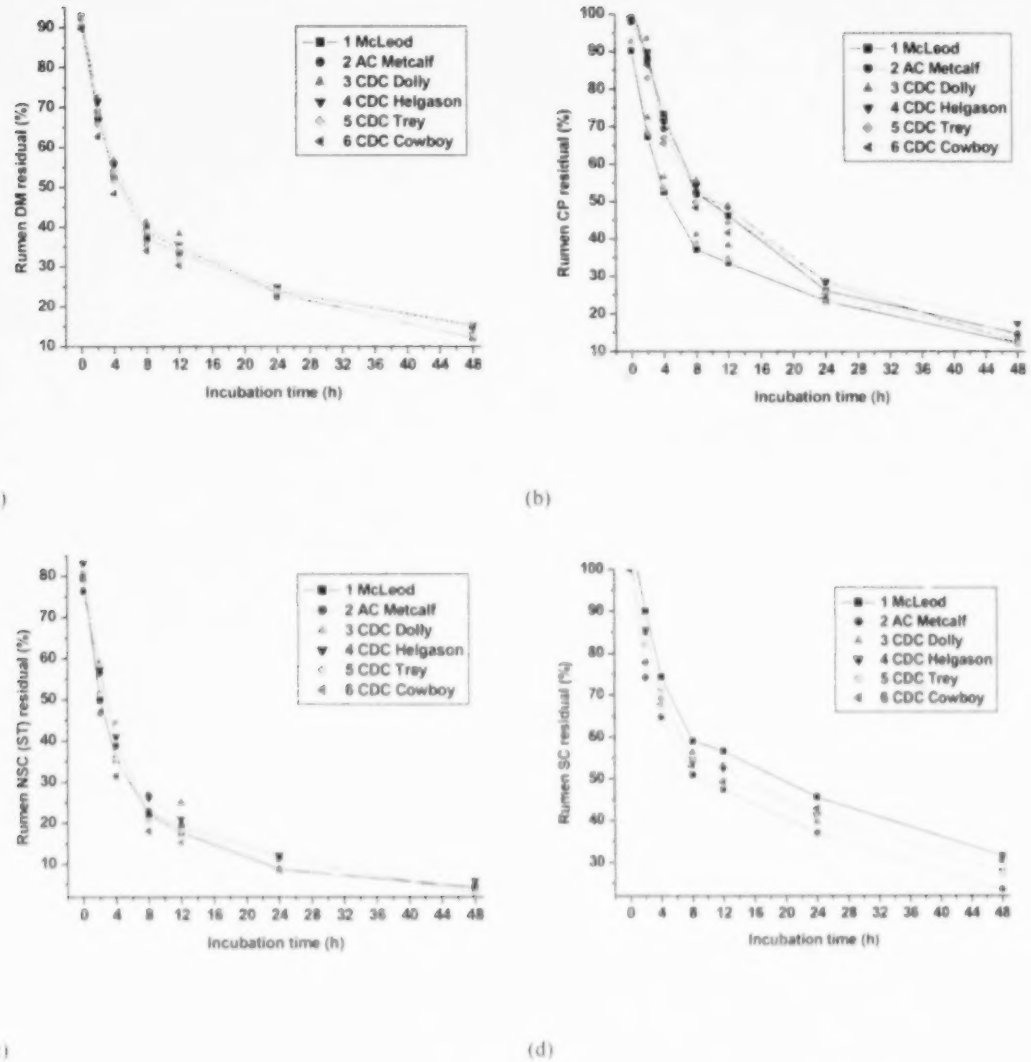

Figure 1. In situ rumen residue (%) of dry matter (DM), crude protein (CP), estimated non-structural carbohydrate (ST), and estimated structural carbohydrate (SC): Comparison of 6 barley varieties growth in western Canada for three consecutive years (2003, 2004 and 2005).

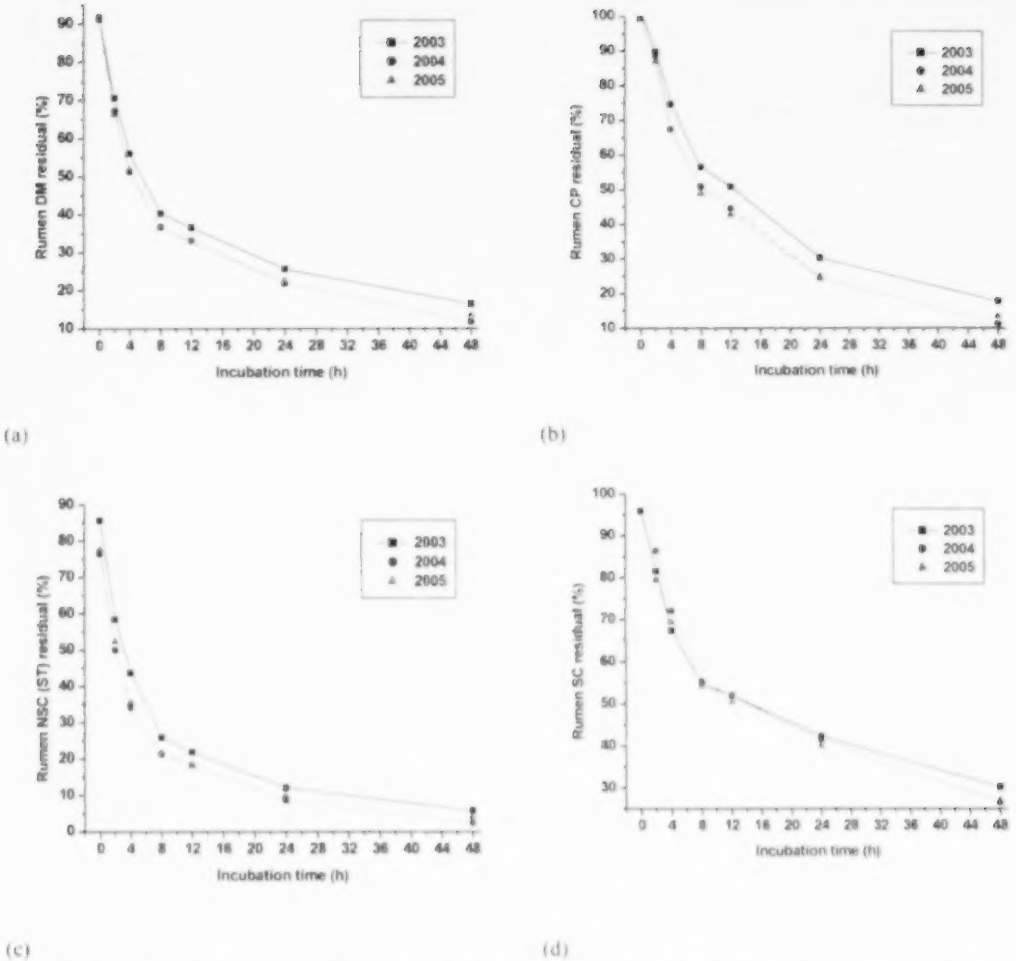

Figure 2. In situ rumen residue (%) of dry matter (DM), crude protein (CP), estimated non-structural carbohydrate (ST), and estimated structural carbohydrate (SC) of 6 barley varieties: Comparison of three years (2003, 2004, 2005).

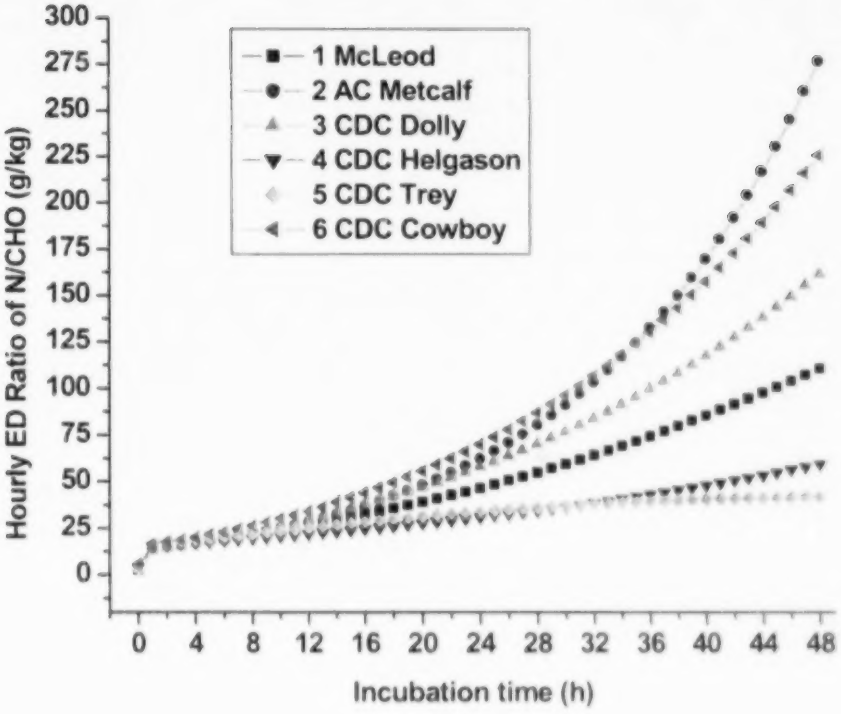

Figure 3. The mean hourly ratio between effectively degraded N and estimated CHO [estimated non-structural carbohydrate (ST) + estimated structural carbohydrate (SC)] of six varieties of barley during three consecutive growth year (2003, 2004, 2005) [Note: hourly effective degradation was estimated as ED = S + D × Kd/(Kd+Kp) × (1- e –t × (Kd+kp)). The difference in cumulative amounts degraded at successive hours was regarded as the amount of degraded each h]

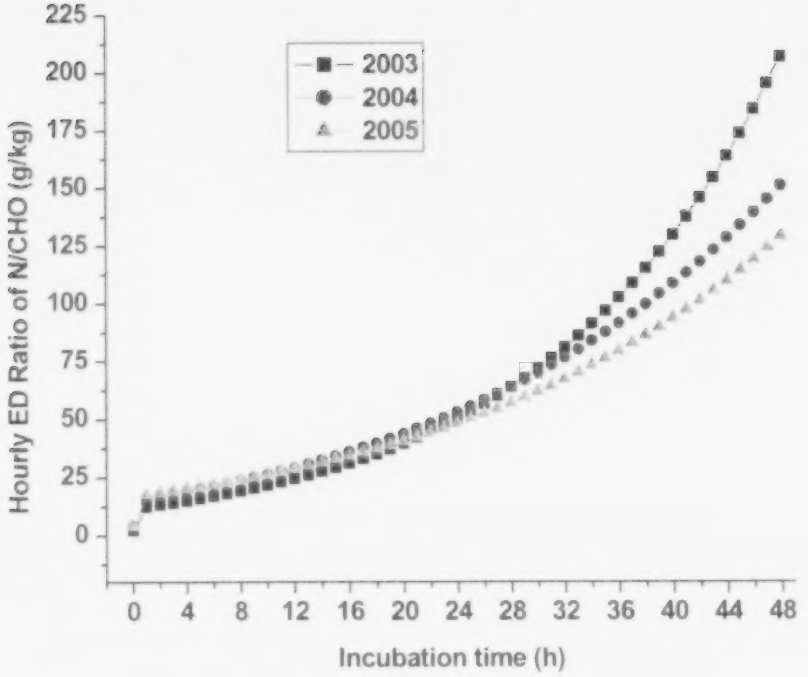

Figure 4. The mean hourly ratio between effectively degraded N and estimated CHO [estimated non-structural carbohydrate (ST) + estimated structural carbohydrate (SC)] of six varieties of barley during three consecutive growth year (2003, 2004, 2005) [hourly effective degradation was estimated as ED = S + D × Kd/(Kd+Kp) × (1- e –t × (Kd+kp)). The difference in cumulative amounts degraded at successive hours was regarded as the amount of degraded each h]

Appendices

Detailed Data Tables:

Table 1. Effect of variety and year on the chemical composition of barley grain (g/kg DM unless otherwise stated)

	Variety								Year				
	AC Metcalf	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*	2003	2004	2005	S.E.M.	*P*
DM (% FW)	94.34	94.18	94.67	94.57	94.79	94.65	0.237	0.500	94.69^{b}	94.10^{a}	94.82^{b}	0.168	0.028
Ash	2.39^{a}	2.58^{b}	2.43^{a}	2.50^{ab}	2.44^{a}	2.59^{b}	0.036	0.013	2.56^{b}	2.53^{b}	2.38^{a}	0.026	0.001
EE	2.04	1.69	1.82	2.53	2.09	1.62	0.141	0.010	2.06	1.98	1.86	0.099	0.422
NDF	18.30^{bc}	13.45^{a}	17.99^{c}	12.97^{a}	12.19^{a}	19.34^{c}	0.403	<0.001	16.45^{b}	15.52^{a}	15.15^{a}	0.285	0.025
ADF	4.64^{b}	4.94^{bc}	3.98^{a}	5.18^{c}	4.91^{bc}	6.59^{d}	0.164	<0.001	5.32^{b}	4.88^{a}	4.93^{a}	0.116	0.045
ADL	2.90	3.12	2.55	2.35	2.52	3.05	0.251	0.245	2.66	2.57	3.02	0.177	0.213
ADF (%NDF)	25.35^{a}	36.90^{bc}	22.13^{a}	39.95^{c}	40.32^{c}	34.12^{b}	1.285	<0.001	32.48	33.19	33.71	0.909	0.646
ADL (%NDF)	15.86	23.97	14.18	18.10	20.84	15.86	2.278	0.092	16.31	17.08	20.98	1.611	0.139
NSC	66.20^{a}	70.30^{a}	66.67^{a}	71.30^{bc}	72.27^{c}	65.51^{a}	0.428	<0.001	68.59	68.64	68.90	0.303	0.740
Starch	49.15^{a}	52.09^{bc}	50.84^{ab}	51.00^{ab}	53.66^{c}	52.57^{bc}	0.749	0.022	50.34^{a}	52.98^{b}	51.34^{ab}	0.530	0.017
Starch (%NSC)	74.25^{ab}	74.11^{ab}	76.26^{b}	71.52^{a}	74.24^{ab}	80.26^{c}	1.145	0.006	73.46^{a}	74.61^{a}	77.24^{b}	0.811	0.022
CHO	83.43^{abc}	82.72^{a}	83.69^{bc}	83.20^{ab}	83.39^{abc}	83.99^{c}	0.237	0.050	84.05^{b}	83.14^{a}	83.02^{a}	0.168	0.003
NFC	66.20^{a}	70.30^{b}	66.67^{a}	71.30^{bc}	72.27^{c}	65.51^{a}	0.428	<0.001	68.59	68.64	68.90	0.303	0.740
Hemi-cellulose	13.66^{c}	8.51^{b}	14.01^{d}	7.79^{ab}	7.28^{a}	8.51^{c}	0.390	<0.001	10.23	10.64	11.13	0.275	0.115
Cellulose	1.74^{ab}	1.82^{ab}	1.43^{a}	2.83^{cd}	2.38^{bc}	3.54^{d}	0.290	0.004	1.91	2.31	2.66	0.205	0.078

Table I. *Cont'd*

	Variety								Year				
	AC Metcalf	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*	2003	2004	2005	S.E.M.	*P*
CP	12.14	13.00	12.06	11.77	12.08	11.80	0.261	0.069	11.33[a]	12.35[b]	12.74[b]	0.185	0.001
TP (%CP)	94.83	95.53	92.95	95.92	94.18	94.57	0.974	0.387	94.42	94.50	95.07	0.689	0.769
NPN	0.64	0.59	0.85	0.48	0.70	0.64	0.123	0.469	0.56	0.69	0.70	0.087	0.470
NPN (%CP)	5.17	7.67	7.05	4.08	5.82	5.43	1.672	0.694	4.93	5.58	7.11	1.182	0.439
SCP	2.28	2.58	2.06	2.39	2.48	2.17	0.109	0.055	2.26	2.27	2.45	0.077	0.190
SCP (%CP)	18.87	19.88	17.09	20.37	20.55	18.54	0.905	0.147	20.04	19.85	17.75	0.640	0.054
ADIP	0.12	0.02	0.01	0.05	0.13	0.04	0.028	0.087	0.04	0.07	0.07	0.020	0.568
ADIP (%CP)	0.84	0.19	0.10	0.38	1.03	0.32	0.970	0.075	0.35	0.54	0.55	0.686	0.629
NDIP	1.07[b]	1.03[b]	0.98[ab]	1.07[b]	1.07[b]	0.86[a]	0.037	0.016	0.98	1.02	1.04	0.026	0.261
NDIP (%CP)	8.80	1.03	8.12	9.12	8.83	0.86	0.970	0.051	8.64	8.31	8.16	0.686	0.443

Table II. Effect of variety and year on the predicted energy content of barley grain

	Variety								Year				
	AC Metcalf	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*	2003	2004	2005	S.E.M.	*P*
Truly digestible fractions (%DM)													
tdNFC	67.47^{a}	71.65^{b}	67.95^{a}	72.67^{bc}	73.66^{c}	66.77^{a}	0.436	<0.001	69.90	69.96	70.22	0.309	0.743
tdCP	11.70^{a}	12.88^{b}	12.00^{a}	11.56^{a}	11.46^{a}	11.59^{a}	0.232	0.013	11.19^{a}	12.02^{b}	12.39^{b}	0.164	0.001
tdFA	1.04^{ab}	0.69^{ab}	0.82^{ab}	1.53^{c}	1.09^{b}	0.62^{a}	0.141	0.010	1.06	0.98	0.86	0.099	0.422
tdNDF	7.49^{b}	4.29^{a}	7.79^{b}	4.73^{a}	4.07^{a}	8.11^{b}	0.463	<0.001	6.65	6.16	5.43	0.327	0.070
TDN	81.99^{b}	83.39^{c}	82.58^{bc}	85.41^{d}	84.65^{d}	80.87^{a}	0.336	<0.001	83.11	83.35	82.99	0.238	0.578
Dairy (Mcal/kg DM; NRC 2001)													
DE 1x	3.60^{ab}	3.68^{cd}	3.63^{bc}	3.74^{e}	3.71^{de}	3.55^{a}	0.016	<0.001	3.64	3.66	3.65	0.011	0.417
DE 3x	3.31^{b}	3.37^{cd}	3.34^{bc}	3.44^{e}	3.41^{de}	3.26^{a}	0.014	<0.001	3.34	3.36	3.36	0.010	0.446
ME 3x	2.89^{ab}	2.96^{c}	2.92^{b}	3.02^{d}	2.99^{cd}	2.85^{a}	0.014	<0.001	2.93	2.95	2.94	0.010	0.383
NE_l 3x	1.84^{ab}	1.89^{cd}	1.86^{bc}	1.93^{e}	1.91^{de}	1.81^{a}	0.010	<0.001	1.87	1.88	1.88	0.007	0.426
DE 4x	3.16^{ab}	3.22^{cd}	3.19^{bc}	3.28^{e}	3.26^{de}	3.12^{a}	0.014	<0.001	3.20	3.21	3.20	0.010	0.458
ME 4x	2.74^{b}	2.81^{c}	2.77^{b}	2.87^{d}	2.84^{cd}	2.70^{a}	0.013	<0.001	2.78	2.79	2.79	0.009	0.431
NE_l 4x	1.74^{b}	1.78^{cd}	1.75^{bc}	1.82^{e}	1.80^{de}	1.71^{a}	0.010	<0.001	1.76	1.78	1.77	0.007	0.375
Beef (Mcal/kg DM; NRC 1996)													
ME	2.95^{ab}	3.02^{c}	2.98^{b}	3.07^{d}	3.04^{cd}	2.91^{a}	0.012	<0.001	2.99	3.00	3.00	0.008	0.392
NEm	1.99^{ab}	2.04^{cd}	2.01^{bc}	2.09^{e}	2.06^{de}	1.96^{a}	0.010	<0.001	2.02	2.03	2.03	0.007	0.527
NEg	1.34^{b}	1.38^{c}	1.36^{b}	1.42^{d}	1.40^{cd}	1.31^{a}	0.008	<0.001	1.36	1.38	1.37	0.006	0.319

Table III. Effect of variety and year on the CNCPS protein and carbohydrate fractions of barley grain

	Variety								Year				
	AC Metcalf	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*	2003	2004	2005	S.E.M.	*P*
Protein fractions (%CP)													
PA	5.17	7.67	7.05	4.08	5.82	5.43	1.672	0.694	4.93	5.58	7.11	1.182	0.439
PB1	13.70	12.21	10.04	16.29	14.73	13.11	1.760	0.277	15.12	14.27	10.65	1.245	0.065
PB2	72.34	72.11	74.79	70.51	70.62	74.12	1.016	0.065	71.32^{a}	71.84^{ab}	74.08^{b}	0.718	0.048
PB3	7.96	7.82	8.01	8.74	7.80	7.02	0.370	0.131	8.29	7.77	7.62	0.261	0.216
PC	0.84	0.19	0.10	0.38	1.03	0.32	0.221	0.075	0.35	0.54	0.55	0.156	0.629
Protein fractions (%TP)													
PB1	14.41	12.75	10.79	17.00	15.64	13.88	1.821	0.295	15.85	15.12	11.27	1.288	0.064
PB2	76.31^{ab}	75.50^{ab}	80.45^{c}	73.49^{a}	74.99^{a}	78.37^{bc}	0.950	0.005	75.08^{a}	76.08^{a}	78.41^{b}	0.672	0.016
PB3	8.38	8.18	8.62	9.12	8.28	7.42	0.381	0.143	8.71	8.24	8.06	0.270	0.265
Protein fractions (%DM)													
PB1	1.64	1.55	1.21	1.92	1.78	1.53	0.226	0.404	1.34	1.71	1.76	0.160	0.177
PB2	8.79	9.38	9.02	8.31	8.53	8.76	0.265	0.160	8.08^{a}	8.87^{b}	9.44^{b}	0.187	0.002
PB3	0.96^{b}	1.01^{b}	0.97^{b}	1.03^{b}	0.94^{b}	0.82^{a}	0.033	0.017	0.94	0.96	0.97	0.023	0.638

Table III. *Cont'd*

	Variety								Year				
	AC Metcalf	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*	2003	2004	2005	S.E.M.	*P*
Carbohydrate fractions (%CHO)													
CA	20.43^{bc}	22.00^{cd}	18.91^{b}	24.41^{d}	22.32^{cd}	15.41^{a}	0.970	0.001	21.72^{b}	18.86^{a}	21.16^{b}	0.686	0.033
CB1	58.91^{a}	63.00^{bc}	60.76^{ab}	61.30^{ab}	64.35^{c}	62.59^{bc}	0.885	0.019	59.89^{a}	63.73^{b}	61.85^{ab}	0.625	0.005
CB2	12.30^{b}	5.94^{a}	13.01^{b}	7.52^{a}	6.07^{a}	13.28^{b}	1.082	0.001	10.80	10.00	8.26	0.765	0.104
CC	8.35	9.06	7.32	6.78	7.26	8.72	0.723	0.242	7.60	7.42	8.73	0.511	0.193
Carbohydrate fractions (%DM)													
CA	6.96	7.49	6.13	5.64	6.06	7.33	0.600	0.244	6.16	6.39	7.24	0.424	0.214
CB1	10.27^{b}	4.93^{a}	10.89^{b}	6.25^{a}	5.06^{a}	11.15^{b}	0.897	0.001	6.87	8.33	9.08	0.635	0.087
CB2	49.15^{a}	52.10^{bc}	50.84^{ab}	51.00^{ab}	53.66^{c}	52.57^{bc}	0.749	0.022	50.33^{a}	52.98^{b}	51.35^{ab}	0.530	0.017
CC	49.15^{a}	52.10^{bc}	50.84^{ab}	51.00^{ab}	53.66^{c}	52.57^{bc}	0.749	0.001	18.25^{b}	15.67^{a}	17.56^{b}	0.572	0.025

Table IV Effect of variety and year on the in situ rumen degradation characteristics of dry matter and crude protein (using the Orskov model) and starch (using the DVE/OEB system)

	Variety								Year				
	AC Metcalf	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*	2003	2004	2005	S.E.M.	*P*
***In situ* rumen dry matter degradation characteristics**													
S (%)	9.65^{b}	10.18^{b}	6.96^{a}	7.80^{a}	9.46^{b}	7.19^{a}	0.397	<0.001	8.50	8.19	8.93	0.296	0.146
D (%)	72.14^{b}	69.71^{a}	75.02^{c}	72.21^{b}	72.48^{b}	72.37^{b}	0.908	<0.001	70.53^{a}	74.19^{c}	72.24^{b}	0.802	<0.001
U (%)	18.20^{a}	20.11^{b}	18.02^{a}	19.99^{b}	18.06^{a}	20.44^{b}	0.757	0.006	20.97^{c}	17.62^{a}	18.82^{b}	0.631	<0.001
K_d (%/h)	16.47^{bc}	21.67^{d}	14.08^{a}	15.69^{ab}	17.82^{c}	17.40^{bc}	1.157	<0.001	15.85^{a}	17.49^{b}	18.22^{b}	1.075	0.001
RUDM (%)	37.52^{bc}	35.54^{a}	40.58^{d}	40.10^{d}	36.52^{ab}	39.07^{cd}	1.091	<0.001	40.66^{b}	36.89^{a}	37.12^{a}	1.020	<0.001
EDDM (%)	62.48^{bc}	64.46^{d}	59.42^{a}	59.90^{a}	63.48^{cd}	60.93^{ab}	1.091	<0.001	59.34^{a}	63.11^{b}	62.88^{b}	1.020	<0.001
***In situ* rumen crude protein degradation characteristics**													
S (%)	2.33	2.68	1.75	1.44	1.71	1.59	1.041	0.955	0.90	2.57	2.28	0.736	0.241
D (%)	84.09^{b}	80.06^{a}	85.01^{b}	79.52^{a}	83.02^{ab}	82.81^{ab}	1.383	0.020	81.04^{a}	84.23^{b}	81.99^{ab}	1.058	0.043
U (%)	13.58^{a}	17.26^{bc}	13.24^{a}	19.04^{c}	15.27^{ab}	15.60^{ab}	1.178	0.001	18.06^{c}	13.20^{a}	15.74^{b}	0.941	<0.001
K_d (%/h)	8.77^{a}	12.67^{c}	8.84^{a}	11.10^{bc}	11.25^{bc}	10.15^{ab}	0.605	<0.001	9.50^{a}	10.46^{ab}	11.44^{b}	0.456	0.005
RUCP (%)	48.22^{c}	43.25^{a}	47.82^{c}	47.29^{c}	44.63^{ab}	46.60^{bc}	1.380	0.001	50.03^{b}	44.47^{a}	44.40^{a}	1.228	<0.001
RUCP (%DM)	5.82	5.59	5.76	5.57	5.39	5.48	0.173	0.110	5.66	5.48	5.66	0.152	0.243
EDCP (%)	51.78^{a}	56.75^{c}	52.18^{a}	52.71^{a}	55.37^{bc}	53.40^{ab}	1.380	0.001	49.97^{a}	55.53^{b}	55.60^{b}	1.228	<0.001
EDCP (%DM)	6.32^{ab}	7.41^{c}	6.30^{a}	6.22^{a}	6.69^{b}	6.31^{ab}	0.182	<0.001	5.67	6.87	7.09	0.155	<0.001
RUCP-dve %DM	6.46	6.20	6.40	6.18	5.98	6.08	0.193	0.110	6.29	6.09	6.28	0.169	0.242

Table IV. *Cont'd*

	Variety								Year				
	AC Metcalf	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*	2003	2004	2005	S.E.M.	*P*
***In situ* rumen starch degradation characteristics**													
S (%)	23.58	19.94	20.96	14.83	18.73	20.22	2.657	0.334	14.33^{a}	23.55^{b}	21.24^{b}	1.879	0.003
D (%)	76.42	80.06	79.04	85.17	81.27	79.78	2.657	0.334	85.67^{b}	76.45^{a}	78.76^{a}	1.879	0.003
K_d (%/h)	14.26^{a}	21.44^{d}	12.13^{a}	14.72^{ab}	17.73^{c}	17.45^{bc}	1.579	<0.001	14.86	17.26	16.74	1.394	0.065
RUST (%)	25.19^{bc}	20.07^{a}	28.66^{d}	26.69^{cd}	22.68^{b}	22.80^{b}	1.273	<0.001	26.66^{b}	22.96^{a}	23.42^{a}	1.100	<0.001
RUST (%DM)	12.39^{bc}	10.41^{a}	14.51^{d}	13.57^{cd}	12.18^{b}	11.96^{b}	0.635	<0.001	13.38^{b}	12.15^{a}	11.98^{a}	0.557	0.004
EDST (%)	74.81^{bc}	79.93^{d}	71.34^{a}	73.31^{ab}	77.32^{c}	77.20^{c}	1.273	<0.001	73.34^{a}	77.04^{b}	76.58^{b}	1.100	<0.001
EDST (%DM)	36.77^{a}	41.69^{b}	36.33^{a}	37.43^{a}	41.47^{b}	40.60^{b}	0.754	<0.001	36.96^{a}	40.83^{c}	39.36^{b}	0.613	<0.001

Table V. Effect of variety and year on the predicted potential nutrient supply to dairy cattle using the NRC and DVE/OEB models (all g/kgDM)

	Variety								Year				
	AC Metcalf	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*	2003	2004	2005	S.E.M.	*P*
Modeling nutrient supply using NRC-2001													
MCP_{EDCP}	53.70^{ab}	62.99^{b}	53.55^{a}	52.89^{a}	56.84^{b}	53.67^{ab}	1.543	<0.001	48.16^{a}	58.43^{b}	60.23^{b}	1.321	<0.001
MCP_{TDN}	97.84^{b}	99.51^{d}	98.55^{c}	101.93^{f}	101.03^{e}	96.51^{a}	0.187	<0.001	99.19	99.46	99.04	0.132	0.082
$MCP_{Supplied}$	53.70^{ab}	62.99^{b}	53.55^{a}	52.89^{a}	56.84^{b}	53.67^{ab}	1.543	<0.001	48.16^{a}	58.43^{b}	60.23^{b}	1.321	<0.001
EDCP-1.18MCP	-52.28^{b}	-43.33^{c}	-53.29^{b}	-58.06^{a}	-52.34^{b}	-50.73^{b}	1.819	<0.001	-60.38^{a}	-48.63^{b}	-46.01^{b}	1.556	<0.001
AMCP	34.37^{ab}	40.31^{c}	34.27^{a}	33.85^{a}	36.38^{b}	34.35^{ab}	0.988	<0.001	30.82^{a}	37.39^{b}	38.55^{b}	0.845	<0.001
RUP	58.19	55.92	57.62	55.70	53.86	54.81	1.732	0.110	56.63	54.85	56.58	1.516	0.243
ARUP	49.47	47.53	48.98	47.34	45.78	46.59	1.472	0.110	48.13	46.62	48.09	1.288	0.243
ECP	11.20^{ab}	11.18^{a}	11.24^{bc}	11.23^{bc}	11.26^{c}	11.24^{bc}	0.013	0.002	11.24^{b}	11.18^{a}	11.26^{b}	0.009	<0.001
AECP	4.48^{ab}	4.47^{a}	4.50^{bc}	4.49^{bc}	4.50^{c}	4.49^{bc}	0.006	0.008	4.50^{b}	4.47^{a}	4.50^{b}	0.004	<0.001
MP	88.32^{b}	92.32^{c}	87.75^{ab}	85.68^{a}	86.66^{ab}	85.44^{a}	0.903	<0.001	83.46^{a}	88.48^{b}	91.14^{c}	0.655	<0.001

Table V. *Cont'd*

	Variety								Year				
	AC Metcalf	CDC Cowboy	CDC Dolly	CDC Helgason	CDC Trey	McLeod	S.E.M.	*P*	2003	2004	2005	S.E.M.	*P*
Modeling Nutrient supply using DVE/OEB system													
FOM	652.67^{c}	652.83^{c}	620.01^{ab}	606.52^{a}	655.37^{c}	635.84^{bc}	13.297	<0.001	601.20^{a}	662.11^{b}	648.32^{b}	11.878	<0.001
E_MCP	97.90^{c}	97.93^{c}	93.00^{ab}	90.98^{a}	98.31^{c}	95.38^{bc}	1.994	<0.001	90.18^{a}	99.32^{b}	97.25^{b}	1.782	<0.001
TPSI	138.02^{d}	135.51^{cd}	133.71^{bc}	130.06^{a}	133.52^{bc}	132.38^{ab}	1.098	<0.001	130.49^{a}	135.37^{b}	135.74^{b}	0.827	<0.001
AMCP	62.41^{c}	62.43^{c}	59.29^{ab}	58.00^{a}	62.67^{c}	60.80^{bc}	1.272	<0.001	57.49^{a}	63.32^{b}	62.00^{b}	1.136	<0.001
DOM	861.50^{c}	835.93^{ab}	847.26^{bc}	829.32^{a}	857.94^{c}	832.56^{a}	6.466	<0.001	818.41^{a}	864.26^{c}	849.59^{b}	5.368	<0.001
UOM	81.88^{a}	105.89^{cd}	99.39^{bc}	116.40^{d}	89.99^{ab}	113.93^{d}	6.355	<0.001	128.45^{c}	76.70^{a}	98.60^{b}	5.316	<0.001
UASH	19.82^{bc}	20.37^{c}	18.68^{a}	18.99^{ab}	18.23^{a}	18.74^{ab}	0.386	0.003	18.61^{a}	20.67^{b}	18.14^{a}	0.273	<0.001
UDM	101.70^{a}	126.26^{cd}	118.07^{bc}	135.40^{d}	108.22^{ab}	132.66^{d}	6.376	<0.001	147.06^{c}	97.36^{a}	116.73^{b}	5.326	<0.001
ENDP	7.63^{a}	9.47^{cd}	8.86^{bc}	10.16^{d}	8.12^{ab}	9.95^{d}	0.478	<0.001	11.03^{c}	7.30^{a}	8.76^{b}	0.399	<0.001
RUP	64.59	62.04	63.96	61.84	59.78	60.83	1.926	0.110	62.85	60.87	62.80	1.686	0.242
ARUP	54.91	52.76	54.37	52.55	50.82	51.72	1.634	0.110	53.43	51.75	53.38	1.430	0.243
N_MCP	56.78^{a}	67.95^{a}	56.66^{a}	56.09^{a}	60.94^{b}	57.11^{ab}	1.972	<0.001	50.44^{a}	62.70^{b}	64.64^{b}	1.705	<0.001
DVE	109.69^{d}	105.72^{c}	104.80^{bc}	100.39^{a}	105.37^{bc}	102.57^{ab}	1.075	<0.001	99.89^{a}	107.76^{b}	106.62^{b}	0.785	<0.001
OEB	-41.12^{a}	-29.97^{d}	-36.34^{bc}	-34.89^{c}	-37.36^{bc}	-38.26^{ab}	1.184	<0.001	-39.75^{a}	-36.61^{b}	-32.61^{c}	0.880	<0.001

Highly Qualified Personal Training from This Project:

- PDF Research Fellow: Dr. Kenton Hart (PhD from UK)
- PDF Research Fellow: Dr. Daalkhaijav Damiran (PhD from USA)

Technology Transfer, Research Publications and Presentations/Seminars

(*Corresponding author)

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